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Local-global visuospatial processing in Autism Spectrum Disorders and Nonverbal Learning Disabilities: A cross-task and cross-disorder comparison

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ABSTRACT

Visuospatial abilities are considered essential to our interaction with the environment and are involved in many every-day activities (Hegarty & Waller, 2005; Jansen, Wiedenbauer, & Hahn, 2010). A useful way to approach this neuropsychological domain is the global-local paradigm, according to which, people may attend an event using a global processing style, in which they consider the *gestalt* of a set of stimuli, or a local processing style, in which they focus on details (Förster & Dannenberg, 2010; Navon, 1977; Schooler, 2002). An abundance of research on global versus local processing has revealed preferential processing styles (with a global or local bias) in specific neurodevelopmental disorders, particularly as concerns Autism Spectrum Disorders (ASD) (Caron, Mottron, Dawson, Bertiaume, & Dawson, 2006; Kuschner, Bodner, & Minshew, 2009). Conflicting findings have often emerged in the literature (see for example Van der Hallen, Evers, Brewaeys, Van den Noortgate, & Wagemans, 2015), however, showing that participants with different developmental disorders can process both global and local information, depending on the task requirements and the cognitive domain involved, but in different and atypical ways (Dukette & Stiles, 2001). These results prevent possible generalizations and need to be further explored. Differently, global and local processing styles have never been studied in children with other neurodevelopmental disorders, such as Nonverbal Learning Disabilities (NLD), even though there is evidence to suggest that the issue could be relevant in individuals with NLD as well (Chow & Skuy, 1999). For this reason, cross-task and cross-syndrome comparisons are suggested as the best way to analyze these processing abilities and reveal

similarities and differences in global and local processing styles in neurodevelopmental disorders (D'Souza, Booth, Connolly, Happé, & Karmiloff-Smith, 2016).

The main aim of this PhD dissertation is to improve our understanding of the role of global and local visuospatial processing in the neuropsychological profile of specific neurodevelopmental disorders, using cross-task and cross-disorder comparisons. Children with ASD without intellectual disability (ID) or NLD were tested in terms of their performance in different domains of visuospatial skills, comparing them with each other and with children who had other neurodevelopmental disorders, such as dyslexia or Attention Deficit Hyperactivity Disorder (ADHD). The assessment focused on visuospatial processing speed, visuo-perceptual and visuo-constructive abilities, visuospatial working memory (VSWM), and their interplay with local and global processing. Based on the modified Block Design Task (BDT) paradigm (Caron et al., 2006), new tasks and stimuli have been devised in order to assess the previously mentioned visuospatial abilities, and four studies have been carried out.

Study I aimed to make a cross-task comparison on global-local visuospatial processing in two groups of participants with ASD without ID – with and without a visuospatial peak (–P and –NP) – comparing them with matched typically developing (TD) individuals. The results helped us to clarify the visuospatial profile of the two groups of individuals with ASD, demonstrating the importance of taking specific factors into account (i.e. the visuospatial domains examined and the perceptual reasoning abilities). Participants with ASD-NP performed poorly in all domains, revealing weaker spatial integration abilities in the visuo-perceptual domain and a diminished sensitivity to perceptual coherence in the VSWM, while the ASD-P group used both global and local processing effectively according to the task, and a local bias only emerged in the visuo-constructive task. In agreement with D'Souza and coauthors (2016), our results support the conviction that labelling individuals with ASD as 'local processors' is restrictive. They may use both local and global processing styles depending on the demands of the task in hand, the visuospatial domain involved and their cognitive visuospatial functioning.

Study II (Chapter 3) aimed to investigate global and local visuospatial processing in children with symptoms of NLD comparing them with children with symptoms of dyslexia and with TD controls. The results showed that children with symptoms of NLD were less accurate in visuo-constructive tasks, while children with symptoms of dyslexia were only slightly impaired in a visuo-constructive task, but clearly slower in the perceptual task. Children with symptoms of NLD were less able to benefit from different levels of coherence of the stimuli, probably as a consequence of their less flexible and efficient visuospatial processes (Mammarella, & Cornoldi, 2005). In particular, the global dominance mechanism (Navon, 1977) made it more complicated for the group with symptoms of NLD to switch from a global to a local processing, which was needed to complete the visuo-constructive task correctly.

After investigating the issue of global and local visuospatial processing separately for ASD without ID and NLD, the aim of Study III (Chapter 4) was to draw a cross-disorders comparison, highlighting similarities and differences across three clinical profiles - ASD without ID, NLD and ADHD - as compared with TD controls. Our results revealed different visuospatial profiles for the groups considered, and suggested the utility of manipulating the coherence of stimuli to investigate visuospatial skills. Marked deficit in all the visuospatial domains emerged for the group with NLD, confirming that impairments in the visuospatial domain are core and distinctive symptoms of this disorder (Cornoldi, Mammarella, & Fine, 2016; Semrud-Clikeman, Walkowiak, Wilkinson, & Christopher, 2010). In addition, difficulty in integrating local configurations in a coherent whole emerged for the visuo-perceptual domain. A heterogeneous profile emerged for children with ADHD, which showed, consistently with previous studies, impairment in the visuospatial processing speed domain and in VSWM (Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005; Weigard & Huang-Pollock, 2017). Moreover, these participants presented some difficulties in visuo-constructive abilities when they had to deal with global configurations, while they performed normally in visuo-perceptual task. Differently, participants with ASD performed normally in all the examined domains, using effectively both global and local visuospatial processes, with the sole exception of the visuo-constructive task in which this group showed slower response times and a diminished sensitivity to perceptual coherence (Caron et al., 2006; Shah & Frith, 1993).

Finally, since individuals with NLD and those with High Functioning Autism or Asperger Syndrome (DSM-IV TR, American Psychiatric Association [APA], 2000) are often confused, Study IV (Chapter 5) included a further comparison between ASD and NLD. Visuo-constructive abilities and VSWM were investigated in a subgroup of participants with ASD without ID and without a visuospatial peak (ASD-NP) and in a group with NLD. Thus, Study IV aimed to analyze whether ASD-NP – though not representative of the ASD without ID population as a whole– shared any characteristics with the NLD group. Once again, our results differentiate the visuospatial profile of children with NLD from that of children with ASD. The former group showed an impaired performance in all the domains examined affecting both global and local levels of processing. The ASD group had a more heterogeneous profile, with normal performance in VSWM and in the drawing of a complex figure, slower response times in the segmented condition of visuoconstructive BDT and a more local and fragmented drawing style in the recall of a complex figure. Here again, local bias affected the performance of participants with ASD in tasks demanding visuoconstructive skills that specifically involved combining parts to form a single whole (Simic, Khan, & Rovet, 2013).

General conclusions derived from the main findings of the four studies, and both clinical and educational implications will be thus highlighted in the final chapter of this dissertation.

To conclude, investigating visuospatial abilities and global-local processing in individuals with neurodevelopmental disorders offer crucial insight for the analysis of the strengths and weaknesses of the clinical profiles examined and for their differential diagnosis. There is still space for further research on the domains of visuospatial abilities, and on the general neuropsychological functioning of children with different neurodevelopmental disorders. This dissertation was an effort to raise and clarify some points, however other questions remain open and will require further studies.

ABSTRACT (Italian version)

Le abilità visuospaziali sono un insieme di abilità considerate essenziali nell'interazione con l'ambiente e sono coinvolte in numerose attività quotidiane (Hegarty & Waller, 2005; Jansen, Wiedenbauer, & Hahn, 2010). Il paradigma di elaborazione globale-locale (Navon, 1977) costituisce un utile approccio per studiare questo dominio neuropsicologico. Secondo tale paradigma le persone possono percepire un evento usando uno stile di elaborazione globale, per cui considerano la *gestalt* di un insieme di stimoli, o uno stile di elaborazione locale, per cui si focalizzano sui dettagli (Förster & Dannenberg, 2010; Navon, 1977; Schooler, 2002). Numerose ricerche sull'elaborazione globale-locale hanno rivelato l'uso preferenziale di uno stile di elaborazione (con un *bias* globale o locale) in specifici disturbi del neurosviluppo, in particolare riguardo al disturbo dello spettro dell'autismo (ASD) (Caron, Mottron, Dawson, Bertiaume, & Dawson, 2006; Kuschner, Bodner, & Minshew, 2009). Tuttavia, risultati conflittuali sono spesso emersi in letteratura (vedi Van der Hallen, Evers, Brewaeys, Van den Noortgate, & Wagemans, 2015) e mostrano come i partecipanti con differenti disturbi dello sviluppo possono elaborare sia informazioni locali che globali, a seconda delle richieste del compito e del dominio cognitivo coinvolto, ma in modi differenti e atipici (Dukette & Stiles, 2001). Questi risultati prevengono possibili generalizzazioni e necessitano di essere ulteriormente esplorati. Al contrario, gli stili di elaborazione globale-locale non sono mai stati studiati in bambini con altri disturbi del neurosviluppo, come il disturbo dell'apprendimento nonverbale (NLD), nonostante evidenze abbiano suggerito che questi aspetti possano essere rilevanti anche nell'NLD (Chow & Skuy, 1999). Per tale ragione,

confronti tra differenti disturbi del neurosviluppo e attraverso l'uso di diversi compiti vengono suggeriti come il metodo migliore per analizzare queste abilità ed evidenziare similitudini o differenze nell'uso degli stili di elaborazione (D'Souza, Booth, Connolly, Happé, & Karmiloff-Smith, 2016).

L'obiettivo principale della presente tesi di Dottorato è quello di migliorare la nostra comprensione del ruolo dell'elaborazione visuospaziale globale-locale nel profilo neuropsicologico di specifici disturbi del neurosviluppo, attraverso la comparazione di diversi disturbi e l'uso di prove differenti. Sono state indagate le prestazioni di partecipanti con ASD senza disabilità intellettiva (ID) o NLD in diversi domini di abilità visuospaziali, confrontandoli tra loro e con bambini aventi altri disturbi del neurosviluppo, come la dislessia o il deficit di attenzione/iperattività (ADHD). L'*assessment* si è concentrato sull'indagine della velocità di elaborazione visuospaziale, delle abilità visuo-percettive, visuo-costruttive e di memoria di lavoro visuospaziale (VSWM). È stata inoltre indagata l'interazione tra le performance in questi domini e l'elaborazione globale-locale. Sulla base del paradigma modificato di disegno con cubi (BDT) (Caron et al., 2006), sono stati elaborati nuovi compiti e stimoli per valutare le abilità visuospaziali menzionate. In particolare, sono stati condotti quattro studi.

Lo Studio I ha indagato gli stili di elaborazione visuospaziale globale-locale in due gruppi di partecipanti con ASD senza ID - con e senza un picco visuospaziale (-P e -NP) - confrontandoli con individui a sviluppo tipico (TD). I risultati hanno permesso di chiarire il profilo visuospaziale dei due gruppi di partecipanti con ASD, dimostrando l'importanza di tenere in considerazione fattori specifici (come i domini di abilità visuospaziali esaminati e le abilità di ragionamento percettivo dei partecipanti). I partecipanti con ASD-NP hanno ottenuto scarsi risultati in tutti i domini, mostrando inferiori capacità di integrazione spaziale nel dominio visuo-percettivo e una ridotta sensibilità alla coerenza percettiva nella VSWM, mentre il gruppo ASD-P ha utilizzato entrambe le strategie di elaborazione globale e locale in modo efficace in base al compito e un *bias* locale è emerso solo nel compito visuo-costruttivo. In accordo con D'Souza et al. (2016), i nostri risultati sostengono la convinzione che etichettare gli individui con ASD come "*local processors*" sia restrittivo. Infatti, essi possono utilizzare entrambi gli stili di elaborazione locale e globale a seconda delle richieste del compito, del dominio visuospaziale coinvolto e del loro funzionamento cognitivo di tipo visuospaziale.

Lo studio II (Capitolo 3) ha indagato l'elaborazione visuospaziale globale-locale nei bambini con sintomi di NLD confrontandoli con bambini con sintomi di dislessia e con TD. I risultati hanno mostrato un'accuratezza inferiore per i bambini con sintomi di NLD nel compito visuo-costruttivo, mentre i bambini con sintomi di dislessia hanno mostrato lievi difficoltà nel compito visuo-costruttivo e una chiara lentezza in quello viuso-percettivo. Inoltre, i bambini con sintomi di NLD si sono mostrati meno in grado di beneficiare dei diversi livelli di coerenza degli stimoli, probabilmente come conseguenza dei loro processi visuospaziali meno flessibili ed efficienti (Mammarella & Cornoldi, 2005). In particolare, il meccanismo di dominanza globale (Navon, 1977) ha reso più complicato per il gruppo con sintomi di NLD il passaggio dall'elaborazione globale a quella locale, necessario per completare correttamente il compito visuo-costruttivo.

Dopo aver esaminato l'elaborazione visuospaziale globale-locale separatamente per ASD senza ID e NLD, lo scopo dello Studio III (Capitolo 4) era quello di effettuare un confronto tra disturbi, evidenziando somiglianze e differenze tra tre profili clinici - ASD senza ID, NLD e ADHD - rispetto ai TD. I nostri risultati hanno rivelato diversi profili visuospaziali per i gruppi considerati e suggerito l'utilità di manipolare la coerenza degli stimoli per l'indagine di tali abilità. Per il gruppo con NLD è emerso un deficit marcato in tutti i domini visuospaziali, a conferma che le difficoltà in tale dominio costituiscono sintomi fondamentali e distintivi di questo disturbo (Cornoldi, Mammarella & Fine, 2016, Semrud-Clikeman, Walkowiak, Wilkinson e Christopher, 2010). Inoltre, per il dominio visuo-percettivo è emersa la difficoltà di integrare le configurazioni locali in un insieme coerente. Per il gruppo con ADHD si è evidenziato un profilo eterogeneo, i partecipanti con tale diagnosi hanno mostrato, in linea con gli studi precedenti, un deficit nel dominio di velocità di elaborazione visuospaziale e nella VSWM (Martinussen, Hayden, Hogg-Johnson & Tannock, 2005, Weigard & Huang-Pollock, 2017). Inoltre, questi partecipanti hanno presentato alcune difficoltà nelle abilità viso-costruttive quando dovevano ricostruire configurazioni globali, mentre sono emerse abilità visuo-percettive in norma. Diversamente, i partecipanti con ASD hanno mostrato prestazioni in norma in tutti i domini esaminati, utilizzando efficacemente processi visuospaziali globali e locali, con l'unica eccezione del compito visuo-costruttivo in cui questo gruppo ha mostrato tempi di risposta più lenti e una sensibilità ridotta alla coerenza percettiva (Caron et al., 2006; Shah & Frith, 1993).

Infine, considerato che i profili di individui con NLD e con autismo ad alto funzionamento o sindrome di Asperger (DSM-IV TR, American Psychiatric Association [APA], 2000) sono spesso confusi, nello Studio IV (Capitolo 5) è stato proposto un ulteriore confronto tra ASD e NLD. Le abilità visuo-costruttive e la VSWM sono state studiate in un sottogruppo di partecipanti con ASD senza ID e senza picco visuospaziale (ASD-NP) e in partecipanti con NLD. Lo scopo era quello di analizzare se il gruppo con ASD-NP - sebbene non rappresentativo dell'intera popolazione con ASD senza ID – condividesse o meno caratteristiche con il gruppo NLD. Ancora una volta, i nostri risultati hanno permesso di differenziare il profilo visuospaziale dei bambini con NLD da quello dei bambini con ASD. Il primo gruppo ha mostrato prestazioni deficitarie in tutti i domini esaminati sia per il livello di elaborazione locale sia per quello globale. Il gruppo con ASD ha mostrato invece un profilo più eterogeneo, con prestazioni in norma nella VSWM e nel disegno di una figura complessa, tempi di risposta più lenti nella condizione segmentata della prova visuo-costruttiva e uno stile di disegno locale e frammentato nel disegno a memoria di una figura complessa. Anche qui, il *bias* locale ha influenzato le prestazioni dei partecipanti con ASD in compiti che richiedevano competenze visuo-costruttive e nello specifico di combinare le parti per formare un unico insieme (Simic, Khan, & Rovet, 2013).

Infine, le conclusioni generali derivate dai principali risultati dei quattro studi e le loro implicazioni cliniche ed educative sono state evidenziate nel capitolo conclusivo della presente tesi.

Per concludere, l'analisi delle capacità visuospaziali e l'elaborazione globale-locale in individui con disturbi del neurosviluppo offrono una visione cruciale per l'analisi dei punti di forza e di debolezza dei profili clinici esaminati e per la loro diagnosi differenziale. C'è ancora molto spazio per ulteriori ricerche sulle capacità visuospaziali e sul funzionamento neuropsicologico generale dei bambini con diversi disturbi del neurosviluppo. La presente tesi ha avuto l'obiettivo di sollevare e chiarire alcuni punti, ma altre domande restano aperte e richiederanno ulteriori studi.

CHAPTER 1

GLOBAL-LOCAL VISUOSPATIAL PROCESSING: WHAT WE KNOW FROM THE LITERATURE

1.1 GLOBAL AND LOCAL VISUOSPATIAL PROCESSING: DEFINITION AND MAIN FEATURES

The world is perceived as hierarchically organized and comprising global percepts that are composed of local details (D'Souza et al., 2016). When individuals perceive a visual scene they can process it locally, analyzing feature-by-feature, or globally, using an instantaneous and simultaneous process (Navon, 1977). The human being's ability to process information at both global and local levels is involved in several situations, such as making classifications, inspecting the details of an environment, perceiving the structure of the visual scene and analyzing visual and spatial information (Förster, 2012; Nayar, Voyles, Kiorpes, & Di Martino, 2017). In psychological terms, people may attend to an event using a global processing style in which they consider the *gestalt* of a set of stimuli or a local processing style in which they focus on details (Förster & Dannenberg, 2010; Navon, 1977; Schooler, 2002). The first process is typically rapid and automatic (Poirel, Pineau, & Mellet, 2008), through its use individuals attend to the entirety of a set of stimuli, establishing spatial relationships and linking local features together in a coherent whole (Kimchi, 1992; Navon, 1977). While the latter is characterized by a focus on details (Förster & Dannenberg, 2010; Navon, 1977; Schooler, 2002), involves selective attention to individual elements of a scene, is slower and cognitively demanding (Nayar, et al., 2017).

The difference between global and local processing is also confirmed by the study of the underlying neural substrates presiding to them (e.g., Conci, Tollner, Leszczynski, & Muller, 2011). EEG studies showed that early visually evoked potentials are responsive to global stimuli and suggested that integrated global object information is already available at the initial pre-attentive stages of processing in visual search (e.g., Conci et al., 2009), while a substantial delay in search for local, as compared to global, targets was found (Conci et al., 2011).

1.2 Developmental trajectories of global and local visuospatial processing

The development of global-local visual processing is considered a hierarchical process, which proceeds with age from a simple perceptual function to more complex integrative processing (Nayar, Franchak, Adolph, & Kiorpes, 2015). Different studies showed that infants and young children rely on local perceptual strategies and attend to individual features of a stimulus, whereas global perception develops later, in older children and adults (Kimchi, Hadad, Behrmann, & Palmer, 2005; Lewis et al., 2004; Neiworth Gleichman, Olinick, & Lamp, 2006; Sherf, Behrmann, Kimchi, & Luna, 2009). However, this profile for the later development of global perceptual abilities is a matter of debate (Nayar et al., 2015). Some findings indicate the presence of global perceptual abilities already from young infancy (Bremner, Slater, Johnson, Mason, & Spring, 2012; Bulf, Valenza, & Simion, 2009), while other studies highlight weak or lacking global processing in 3- to 5-year-olds children (Abravanel, 1982; Kovács, Kozma, Feher, & Benedek, 1999). To clarify these conflicting findings, a recent study (Nayar et al., 2015) was conducted with the intention of investigate the developmental trajectory of global processing in children and adults. Results showed strong converging evidence for a developmental trajectory from a primarily local processing strategy to global perception.

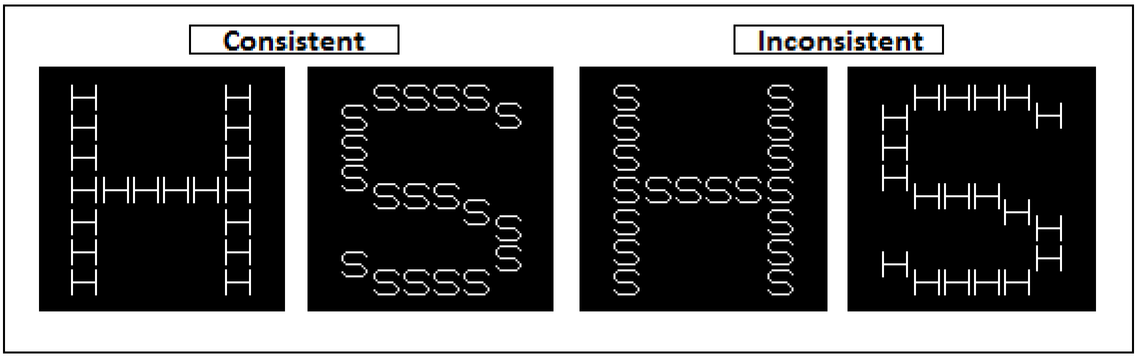
In particular, consistently with other studies, evidence for a gradual shift from a local to a global perceptual strategy were showed in the period between 4 and 7 years and adult-like skills were found in children by 7–8 years of age (Kaldy & Kovacs, 2003; Poirel et al., 2008; Hadad, Maurer, & Lewis, 2010).

In conclusion, it is possible to state that normally from about 7-8 years of age, when a general configuration is presented, the global processing of a stimulus tends to precede the processing of its local features, but only the integration of both levels of information contributes to the complete representation of the visual scene (Kimchi, 1992).

1.3 Paradigms and tasks for the investigation of global and local visuospatial processing in typical and atypical development

Even though the distinction between global and local processing was captured a long time ago and was taken up by Gestalt psychology, it received even more attention after Navon's (1977) research (Förster, 2012). The classic experiment that best illustrates the distinction between global and local visual processes is Navon's global-local paradigm dating from 1977 (Förster & Dannenberg, 2010; Cassia, Simion, Milani, & Umiltà, 2002). In this task, hierarchically constructed stimuli with an overall configuration (global level) comprised of elemental details (local level) were presented on a screen (see Figure 1.1). Compound letters consisted of a number of small capital Ss or Hs (local letters) configured to form either a global S or H and the two level of the images (local and global) were consistent (Ss or Hh) on half of the trials and inconsistent (Sh or Hs) on the other half (Duchaine, Yovel, & Nakayama, 2007). Participants were required to make a key press to indicate whether an S or an H was presented at the global level (Global-directed condition) or at local level (Local-directed condition). By presenting his paradigm, Navon (1977) demonstrated that participants were quicker to identify the global rather than the local target letters and concluded that typically global aspects of a stimulus are analyzed before its local features. Basing on this result the author suggested the existence of a sequential processing, from the global to the local level, providing evidence for a global dominance hypothesis (Forster & Higgins, 2005).

Figure 1.1 Examples of stimuli drawn from Navon's paradigm for both consistent and inconsistent conditions.

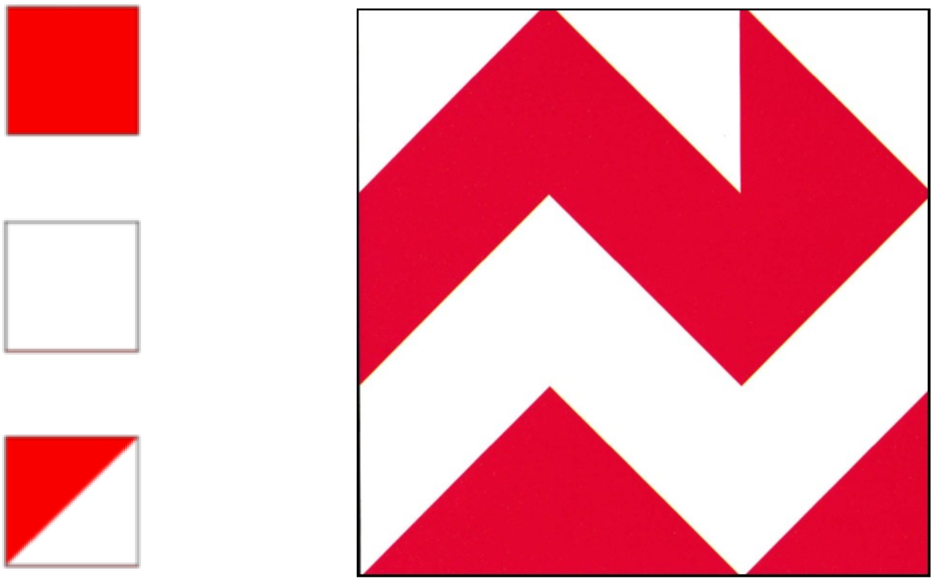


Global versus local processing has generated an abundance of research investigating its effects and researchers challenged the global dominance hypothesis (Forster & Dannenberg, 2010). But although some studies showed that stimulus characteristics (e.g. size, visual angle, eccentricity, distinctiveness of elements, attentional demands, and sparsity of elements) appear to moderate the relative perceptual advantage of global configurations over local elements (Grabowska & Nowicka, 1996; Han & Humphreys, 2002; Kimchi, 1992), the global-advantage has been replicated in numerous studies (for a review, see Kimchi, 1992). As such, it appears to be a reliable finding (Basso & Lowery, 2004).

Modified versions of the Navon paradigm were applied to the investigation of processing styles not only in typical development but also concerning different neurodevelopmental disorders and various domains of cognition such as visual–perceptual processing, visuospatial construction, music perception, and coherence and comprehension in language (Booth & Happé, 2010). Interestingly, some clinical populations, such as children with Autism Spectrum Disorders (ASD) (Happé, 1999; Caron et al., 2006), Williams syndrome (WS) (Farran, Jarrold & Gathercole, 2003), or Down syndrome (DS) (Bellugi, Lichtenberger, Jones, Lai, & St George, 2000), did not show the classical global effect theorized by Navon (1977). Dissociations between global and local processing have been reported in these three developmental disorders (Porter & Coltheart, 2006): people with WS or ASD preferentially process local information showing an abnormal bias toward local processing (e.g., Farran et al., 2003; Caron et al., 2006), while people with DS are reported to favor global information at the expense of local processing (e.g., Bihrle, Bellugi, Delis, & Marks, 1989). In particular, investigating perception, attention and construction abilities through the use of hierarchical stimuli, Porter and Coltheart (2006) found a global bias for individuals with DS and a local bias for individuals with ASD and WS only for the domain of attention. As for perceptual integration and constructional integration using Navon-type stimuli, heterogeneous results emerged for individuals with WS and no local or global bias emerged for ASD and DS (Porter & Coltheart, 2006). Global and local processing was examined also in participants with Attention Deficit Hyperactivity Disorder (ADHD) using Navon-type hierarchical letters. A lack of global precedence and global-to-local interference without local processing deficit was found, suggesting that people with ADHD experience difficulties in processing the "whole picture" (Song & Hakoda, 2015).

Several other visual tasks have been used to investigate global and local processing styles, such as the embedded figures task (Shah and Frith, 1983; Jolliffe & Baron-Cohen, 1997), the impossible figures task (Mottron, Belleville, & Ménard, 1999), and the maze-map task (Caron, Mottron, Rainville, & Chouinard, 2004) and mixed findings often emerged. In particular, a popular visual task extensively used in literature to compare local vs global processing in neurodevelopmental disorders is the 'block design' subtest (BDT) from the Wechsler Intelligence Scales (WISC, WAIS: Wechsler, 2003, 2008). In this task, participants are required to construct figures using the different sides of cubes, which could be monochromatic or bicolor (see Figure 1.2).

Figure 1.2 Examples of the different sides of the cubes (on the left) and of a stimulus (on the right) drawn from the Block Design Task (BDT) of the Wechsler Intelligence Scales (WISC, WAIS: Wechsler, 2003, 2008).



Modified versions of the BDT were used to explore the global/local visuospatial processing, manipulating the perceptual coherence of the stimuli presented. Several studies reported in particular for individuals with ASD (see Study 1 reported in Chapter 2 of the present thesis for a thorough discussion of the issue) a diminished sensitivity to perceptual coherence and a locally oriented approach to processing visuospatial material using the BDT (Caron et al., 2006; Happé & Frith, 2006). In other words, individuals with ASD showed superior performance in this task because they found it easier to divide a whole into parts due to their local bias (Shah & Frith, 1993). Despite this paradigm was applied mainly to studies concerning participants with ASD, studies on block construction tasks were conducted also with other groups. For example, a poor performance was detected in individuals with WS (Farran, Jarrold, & Gathercole, 2001) who seem to show a local processing bias in constructional but not in perceptual levels (Farran & Jarrold, 2003). Consequently, when a BDT is presented, participants with WS could have difficulties in the first step of the task, in which they have to break up each global design presented into logical units to understand what face of the cube they have to choose (Farran & Jarrold, 2003). Finally, in children with Nonverbal Learning Disability (NLD) poor performance in BDT were also found (Mammarella & Cornoldi, 2014), but no studies have explored the effects of perceptual cohesiveness and global or local processing styles in individuals with NLD, despite this distinction proving crucial when examining the perceptual difficulties associated with other related developmental disabilities (e.g. Happé, 1999), and despite evidence suggesting that it could be relevant in the case of NLD as well (Chow & Skuy, 1999). For example, poor performance in *gestalt* configuration tasks and in reversing an ambiguous figure emerged for children with NLD in previous researches (Chow & Skuy, 1999; Mammarella & Pazzaglia, 2010).

1.4 General aim of the present dissertation

The global-local paradigm represents a useful tool for assessing the neuropsychological functioning, with applications across a range of psychological phenomena (Roalf, Lowery, & Turetsky, 2006) including spatial perception (Delis et al., 1992; Kramer, Kaplan, Blusewicz, & Preston, 1991), spatial orientation (Basso & Lowery, 2004), and neurodevelopmental disorders (Porter & Coltheart, 2006; Song & Hakoda, 2015). Despite the study of global-local processing revealed preferential processing style (global or local bias) in some neurodevelopmental disorders, with particular reference to ASD, conflicting findings often emerged in literature (see for example Van der Hallen et al., 2015), which prevent possible generalizations and need to be further explored. In addition, a lack of research emerged on this issue in NLD, despite some evidence suggested that the study of global and local processing could be relevant in its case as well (Chow & Skuy, 1999).

Interestingly, a more recent study (D'Souza et al., 2016) proposed to rethink the concepts of 'local or global processors', based on evidence that participants with different developmental disorders can all process both local and global information, depending on the task, but in different and atypical ways. In fact, depending on task requirements and cognitive domain involved, individuals could use local or global processing showing different performance (Dukette & Stiles, 2001). For this reason, cross-task and cross-syndrome comparisons are suggested as a best practice to better analyze these processing abilities and reveal similarities and differences in global-local processing in neurodevelopmental disorders (D'Souza et al., 2016).

Based on these premise the main aim of this PhD dissertation is to increase the current understanding of the role of global-local visuospatial processing in the neuropsychological profile of specific neurodevelopmental disorders using cross-task and cross-disorder comparisons. Specifically, the performance of children with ASD without intellectual disability (ID) and NLD will be investigated in different domains of visuospatial skills and will be compared with each other and with those of children with other neurodevelopmental disorders, such as dyslexia and ADHD. The paradigm of the BDT (one of the most popular tasks for investigating local vs global visuospatial processing) will be used to select tasks from the literature (Caron et al., 2006), or devise new tasks ad hoc for the studies. Using a solid paradigm to construct all the tasks, and exploring a wide range of visuospatial domains could help to contain the variability of the results and to highlight specific effects for each domain. In particular, visuospatial processing speed (i.e., speed and efficiency in processing visuospatial information; Kirchner & Thorpe, 2006), visuo-perceptual (i.e., the ability to perceptually analyze and discriminate objects or images; Menken, Cermak, & Fisher, 1987), visuo-constructive abilities (i.e., skills needed to put parts together to form a single whole; Simic, Khan, & Rovet, 2013) and visuospatial working memory (VSWM, the ability to contemporarily maintain and process visuospatial information; Logie, 1995; Mammarella, Borella, Pastore, & Pazzaglia, 2013) and their interplay with local and global processing will be investigated.

The series of studies which will be presented in this dissertation could lead to new findings allowing an in-depth analysis of different subsystems of the visuospatial domain with immediate clinical implications. Firstly, our findings might help clinicians in the differential diagnosis of individuals with ASD and NLD - two disorders that have posed a diagnostic challenge because of their similarities in some symptoms (e.g., Cornoldi et al., 2016; Williams, Goldstein, Kojkowski, & Minshew, 2008) - by identifying strengths and weaknesses of their cognitive profiles. Secondly, a clear distinction between the visuospatial profiles of children with NLD and those with ASD could shed further light on the consequent refinement of intervention programs.

1.5 Overview of chapters

Different domains of visuospatial skills will be compared in children with different neurodevelopmental disorders in the following chapters. Table 1.1 summarizes the main characteristics of the groups in the four studies, the main aims and the hypotheses of each research that will be presented in details in this PhD dissertation.

Chapter 2 will initially define and describe the principal characteristics of the ASD and the issue of global-local visuospatial processing in this disorder, focusing on the state of the art and on the main methodological issues that can be raised. In the second part of this chapter the first Study will be presented, which aims to make a cross-task comparison on global-local visuospatial processing in ASD without ID considering the role of the perceptual reasoning index (PRI). Participants with ASD with and without a PRI peak (–P and –NP), will be compared with matched typically developing individuals (TD-NP and TD-P). Specifically, the ASD-P group (with a visuospatial peak) will involve individuals with ASD reporting a level of performance in the PRI of the Wechsler Intelligence Scales (WISC or WAIS, depending on the participants' chronological age; Wechsler, 2003, 2008) higher than one standard deviation ($\geq$115) compared to the normative sample, while the ASD-NP group will involve participants with average scores in the PRI. Processing speed, visuo-perceptual, visuo-constructive and visuospatial working memory (VSWM) will be investigated in these groups using a battery of tasks devised with the modified BDT paradigm.

Chapter 3 will first describe the NLD profile, paying particular attention to the definition and the main clinical features. Secondly, the second Study of the present dissertation will be presented, which aimed to investigate global-local visuospatial processing in children with symptoms of NLD. In particular, the performance of children with symptoms of NLD will be compared with those of children with symptoms of dyslexia and with typically-developing (TD) controls. Participants will be presented with a modified BDT, in both a typical visuo-constructive version and a perceptual version.

After investigating in previous chapters the issue of global-local visuospatial processing separately for ASD without ID and NLD, **Chapter 4** will focus on a cross-disorders comparison involving participants with ASD without ID, NLD and ADHD and comparing them with TD controls. Similarities and differences between the clinical groups considered will be first described. Secondly, the third Study of the present dissertation will be presented, which aims to investigate visuospatial processing in children with ASD without ID, NLD and ADHD. In particular visuospatial processing speed, visuo-perceptual, visuo-constructive and VSWM abilities and their interplay with local and global processing will be examined using a battery of tasks devised with the modified BDT paradigm.

Chapter 5 will present the fourth Study that aimed to investigate visuo-constructive abilities and VSWM, and how they relate to global vs local processing, comparing the performance of a subgroup of participants with ASD without ID selected for low PRI scores, NLD and TD controls, in order to understand whether this subgroup of ASD – although not representative of the ASD without ID population – share or not characteristics with the NLD group in the domains examined.

Chapter 6 will summarize the main findings from each study (Chapters 2-5), will describe studies strengths and limits, by also considering open questions and suggestions for further research. Finally, both clinical and educational implications of the current studies will be discussed.

Table 1.1 Summary of the essential information concerning each study: number of participants (N), groups involved, visuospatial domains examined and main aims.

Study	N	Groups	VS domain	Aims	Hypothesis
I	77	ASD-P ASD-NP TD-P TD-NP	VPST Visuo-perceptual Visuo-constructive VSWM	• Analyzing strengths and weaknesses in the visuospatial profile of each ASD group, considering the role of their PRI level; • Investigating whether local/global processing differently affects each domain (D'Souza et al., 2016).	• ASD-P and -NP would show a local bias compared to TD (Caron et al., 2006; Happé & Frith, 2006); • Participants with a PRI peak would show a larger bias towards local processing than the -NP group (Caron et al., 2006); • We expect better performance in all domains for the –P groups and performance less accurate for the –NP groups.
II	60	NLD S. Dyslexia S. TD	Visuo-perceptual Visuo-constructive	• Exploring whether children with NLD or dyslexia have specific impairments in the two domains; • Analyzing the use of global/local processing styles and seeing whether it affects the children's performance differently.	• NLD S. would show difficulty in the visuo-constructive task, but not necessarily in the perceptual task. They would be less able to adapt their visual processes to the PC levels of the stimuli (Cornoldi et al., 2016); • For the Dyslexia S. group the previous mixed findings prevent preliminary hypothesis.
III	193	ASD NLD ADHD TD	VSPS Visuo-perceptual Visuo-constructive VSWM	• Highlighting similarities and differences between the groups, identifying their strengths and weaknesses by domain; • Analyzing the role of global/local processing style, exploring whether it affects the groups' performance in the tasks differently or to the same extent.	• ASD would show performance comparable to TD in the all VS domains and bias towards local processing is expected in the visuo-constructive task. • NLD would show worse performance in all the VS domains (Mammarella & Cornoldi, 2014; Semrud-Clickeman, et al., 2010) for both global and local stimuli. • ADHD would show difficulties in VSWM and VSPS tasks (Martinussen et al. 2005; Weigard & Huang-Pollock, 2017).
IV	56	ASD-NP NLD TD	Visuo-constructive Visuomotor VSWM	• Examining the existence of possible overlaps between ASD-NP and NLD in the three domains; • Highlighting the influence of local bias on participants' performance, depending on the domain.	• ASD-NP would show a heterogeneous VS profile with normal accuracy in BDT, impairment in the ROCFT and slight impairments in VSWM; and a more locally-oriented processing (Caron et al., 2006; Happé & Frith, 2006); • For NLD we expect poor performance in all VS domains (Mammarella & Cornoldi, 2014) for both global and local stimuli.

Note: ASD-P: Autism spectrum disorders with visuospatial peak; ASD-NP: Autism spectrum disorders without visuospatial peak; TD-P: Typical development with visuospatial peak; TD-NP: Typical development without visuospatial peak; NLD S: Symptoms of nonverbal learning disabilities; Dyslexia S: Symptoms of dyslexia; TD: Typical development; ASD: Autism Spectrum Disorders; NLD: Nonverbal learning disabilities; ADHD: Attention deficit hyperactivity disorder; VPST: Visuospatial processing speed task; VSWM: Visuospatial working memory; PRI: Perceptual reasoning index; PC: Perceptual Cohesiveness.

CHAPTER 2

STUDY I

CROSS-TASK COMPARISON ON GLOBAL-LOCAL VISUOSPATIAL PROCESSING IN ASD WITH AND WITHOUT A VISUOSPATIAL PEAK

2.1 Introduction

Autism Spectrum Disorders (ASD) represent a heterogeneous set of neurodevelopmental disorders characterized by deficits in social communication, social interaction and obsessive/stereotyped patterns of behavior, interests or activities (American Psychiatric Association, APA, 2013). Beside the social impairments, also non-social factors play an important role in the cognition of children with ASD.

One of the features of the cognitive and behavioral phenotype of this disorder is the presence of atypical perceptual processes. In fact, several studies reported evidence of peculiarities in the processing of complex visual stimuli in individuals with ASD: a local processing bias is often reported, although conflicting findings emerged (Caron et al., 2006; Kuschner et al., 2009).

The first part of the present chapter is devoted to briefly define and describe the principal characteristics of the ASD: definition, clinical features, prevalence and etiology. In addition, the topic of global-local visuospatial processing in ASD is presented with particular attention to the state of the art and to the main methodological issues that can be raised. The second part presents the first Study, which aimed to make a cross-task comparison on global-local visuospatial processing in ASD without intellectual disability (ID) considering the role of the perceptual reasoning index (PRI). In this study participants with ASD with and without a PRI peak (-P and –NP), were compared with matched typically developing individuals (TD-NP and TD-P). Processing speed, visuo-perceptual, visuo-constructive and visuospatial working memory (VSWM) tasks have been proposed.

2.2 AUTISM SPECTRUM DISORDERS: DEFINITION AND MAIN FEATURES

As above reported, the term ASD refers to individuals with a neurodevelopmental disorder characterized by a set of heterogeneous symptoms. The core features, according to recent diagnostic criteria (DSM-5), are represented by early-onset persistent difficulties in social communication and social interaction and unusually restricted, repetitive patterns of behavior, interests or activities (APA, 2013). In addition, there are various important behavioral and cognitive characteristics associated with ASD, such as motor abnormalities and excellent attention to details (Lai, Lombardo, & Baron-Cohen, 2014), abnormalities of sensory processing (Hazen, Stornelli, O'Rourke, Koesterer, & McDougle, 2014; Klintwall et al., 2011), impaired social cognition and social perception, executive dysfunction, and atypical local vs. global perceptual and information processing (Takahashi, Kamio, & Tobimatsu, 2016). ASD is known as a permanent disability that severely affects individuals throughout childhood, adolescence and adulthood (Takahashi et al., 2016). The symptoms emerge during the early developmental period and represent a clinically significant challenge to the individual's ability to function in daily life (Granpeesheh, Maixner, Knight, & Erickson, 2014). However, the difficulties may not become fully manifest until social demands exceed limited capacities, or may be masked by learned strategies in later years of life (APA, 2013).

Studies have demonstrated that a diagnosis of ASD can be reliably made before two years of age, showing a good stability for diagnoses made in younger siblings as early as 18–24 months of age (Ozonoff et al., 2015). However, a substantial subset of children with ASD (38%–46%) did not receive the first diagnosis until age 3, with higher functioning children over-represented in this later-diagnosed group (Brian et al., 2016).

The term "spectrum" refers to a continuum of symptoms characterized by a great deal of variation in their presence and severity, ranging from severe and pervasive to low severity level, or high-functioning. For this reason, the DSM-5 (APA, 2013) includes specifiers to be used for diagnosis that rate the severity of symptoms on a scale with 3 levels, from "requiring support" (level 1) to "requiring very substantial support"(level 3). In addition, is required to specify if the disorder is accompanied or not with (a) intellectual disability, (b) language impairment, (c) a known medical or genetic condition or environmental factors and (d) another neurodevelopmental or behavioral disorder (APA, 2013).

Comorbidity is quite frequently observed in ASD; individuals with this diagnosis often exhibit symptoms of other neurodevelopmental disorders and neurological or psychiatric conditions (Leyfer et al., 2006). ASD is frequently associated with intellectual disability, language disorder, ADHD, developmental coordination disorder and learning difficulties. In addition, many individuals with ASD have psychiatric symptoms, anxiety and depressive disorders. Finally, medical conditions commonly associated with ASD include epilepsy, sleep problems, and constipation and other comorbid diagnoses (APA, 2013).

Since individuals with ASD often manifest characteristics of other disorders that make it difficult to establish a clear diagnosis, it is necessary to use a multidisciplinary diagnostic assessment and a developmental framework of an interview with the parent or caregiver, direct interaction with the individual, cognitive assessments, a medical examination and collection of information about behavior in community settings (Ozonoff, Goodlin-Jones, & Solomon, 2005; Takahashi et al., 2016).

2.2.1 Prevalence, etiology and risk factors

ASD occurs in all racial, ethnic, and socioeconomic groups (Jo et al., 2015). In recent years, prevalence studies for this disorder have shown a steady increase of its prevalence since the first epidemiological study (Lai et al., 2014; Lotter, 1966). Actually, studies conducted across Asia, Europe, and United States have reported frequencies between 1% and 1.5% (APA, 2013; Christensen et al., 2016). The rise of prevalence is found particularly in individuals without ID, partly due to improved awareness and recognition, changes in diagnosis, and younger age of diagnosis (Takahashi et al., 2016). The incidence is four times more common among males than females (Takahashi et al., 2016). However, females with autism might be under-recognized (Baron-Cohen, Lombardo, Auyeung, Ashwin, Chakrabarti, & Knickmeyer, 2011) and usually high-functioning females are diagnosed later than males (Begeer et al., 2013; Giarelli et al., 2010).

Despite the intense research focus on ASD, the etiology of this disorder remains however poorly defined, research points to a combination of genetics and environmental risk factors (Sealey et al., 2016). The prevailing research on causes of autism points to the idea of an epigenetic mechanism by which aberrant environmental factors trigger gene expression and the resultant appearance of autism symptoms (Kroncke, Willard, Huckabee, 2016). Risk factors for autism may include familial or environmental factors, such as advanced paternal age, maternal obesity or metabolic conditions, having a sibling or parent with autism, maternal exposure to environmental toxins, frequent illnesses in utero or in early infancy, low birth weight, or fetal exposure to valproate, heavy metals or pesticides (APA, 2013; Kroncke et al., 2016).

2.2.2 Global-Local visuospatial processing in ASD: previous findings, theoretical framework and methodological issues

The human being's ability to process information at both global and local levels is important in several situations, such as making classifications or analyzing the details of the environment (D'Souza et al., 2016). Concerning specifically visuospatial stimuli, people may use global or local visual processing styles (Förster & Dannenberg, 2010). By using a global processing style, individuals attend to the gestalt of a set of stimuli, establishing spatial relationships and linking local features together in a coherent whole (Kimchi, 1992; Navon, 1977). A local processing style is characterized instead by a focus on details (Förster & Dannenberg, 2010; Navon, 1977; Schooler, 2002). Use of the former style is typically rapid and automatic, while the latter is slower and cognitively demanding (Nayar et al., 2017). That is why people presented with a general configuration normally tend to use a global rather than a local processing style (global dominance hypothesis; Navon, 1977). Several studies have shown, however, that this does not seem to occur with certain clinical populations, such as individuals with ASD (Happé, 1999; Caron et al., 2006).

Individuals with ASD often present sensory abnormalities and atypical perceptual processes (APA, 2013; Marco, Hinkley, Hill, & Nagarajan, 2011), showing peculiarities in their processing of complex visual stimuli (Caron et al., 2006; Kuschner et al., 2009). In particular, a diminished sensitivity to perceptual cohesiveness and a locally-oriented processing of visuospatial material is reportedly a feature of their cognitive profile (Caron et al., 2006; Happé & Frith, 2006; Mottron, Burack, Iarocci, Belleville, & Enns, 2003).

In other words, individuals with ASD – even those without ID – focus more on processing local details than the scene as a whole (Brosnan, Scott, Fox & Pye, 2004; Happé & Frith, 2006; Wang, Mottron, Peng, Berthiaume & Dawson, 2007). This phenomenon was initially explained by the weak central coherence theory (WCC; Frith, 1989) as a detail-focused processing style characteristic of the disorder. According to this theory, individuals with autism exhibit a weak drive for coherence and a preference for processing parts over wholes, at the expense of higher level meaning, differently from typically developing individuals who exhibit a natural propensity for coherence (Pellicano, Maybery, Durkin, & Maley, 2006). In particular, the WCC model (Frith, 1989; Frith & Happé, 1994) sought to explain the relative superiority of individuals with autism in tasks where a local processing bias is beneficial. For example tasks that involved detecting visual elements embedded in larger fields (Caron et al., 2006), visual searching (O'Riordan, Plaisted, Driver, & Baron-Cohen, 2001), or discriminating patterns or grating (Bertone, Mottron, Jelenic, & Faubert, 2005; Plaisted, O'Riordan, & Baron-Cohen, 1998), as well as in block design, impossible figures, and embedded figures tasks (see Happé & Frith, 2006 for a review). Similarly, this theory accounts for the relative poor performance of individuals with autism in tasks requiring a global processing, when the integration of information is required (e.g. canonical dot counting and integrating fragments of objects) (Pellicano et al., 2006). Later, a modified version of the WCC theory (Happé & Frith, 2006) was proposed, which claimed that the local processing bias in individuals with ASD can be overcome in tasks with explicit demands for global processing. However, studies based on the enhanced perceptual functioning model (EPF; Mottron & Burack, 2001), have suggested a different conceptualization. According to this model, individuals with ASD do not necessarily have difficulty in perceiving global form, but they have an over-specialized perceptual system that, depending on the requirements of a task, may easily interfere with higher-level cognition (Mottron & Burack, 2001; Mottron, Dawson, Soulieres, Hubert, & Burack, 2006). In other words, higher-order control over perception is not mandatory in autism when it interferes with performance of tasks that can be more easily processed locally or using a low-level processing mode (Mottron et al., 2006). On the contrary, the involvement of higher-order control is mandatory in typically developing individuals even when it is detrimental to performance. Given this information, it would seem that individuals with ASD display a relative autonomy of perceptual processes from top-down influences (Caron et al., 2006; Souliéres et al., 2009) and a better access to the processing of material typically masked by top-down influences (Wang et al., 2007). Interestingly, a more recent study (D'Souza et al., 2016) examining global-local processing proposed to rethink the concepts of 'local or global processors', basing on evidences that participants with ASD, William Syndrome or Down Syndrome can all process both local and global information, depending on the task, also if they do so in different and atypical ways. Thus authors conclude that the use of a cross-task design could be useful in better analyze these processing abilities.

Based on these premises it is important to note that despite different theories have sought to provide a framework for this phenomenon, the research literature on local and global processing in individuals with ASD has reported mixed findings (see Van der Hallen et al., 2015 for a review), which need to be further explored. This could be due to different methodological issues.

The first important variable is the broad variability in the cognitive levels of the samples of individuals with ASD considered, particularly as regards their perceptual reasoning skills (Williams, Goldstein, & Minshew, 2006a). In fact, it is rare to find studies on the visuospatial processing of individuals with ASD that compared the performance of groups with different cognitive levels, and especially those without ID. To our knowledge, only a study compared the locally-oriented visuospatial processing of two groups of individuals with high-functioning autism (HFA), divided according to their visuospatial abilities, i.e. those with versus without a visuospatial peak (see Caron et al., 2006). The results showed that both groups exhibited a diminished influence of global dominance, particularly in the modified block design task (BDT). Their different visuospatial abilities seemed to have a role in the other tasks, however, that involved matching block patterns at global level, memorizing global figures, and detecting conjunctive patterns in a visual search task, in which their performance was in line with that of matched typically-developing (TD) groups. These results are interesting, but the small number of participants (8 for each group with ASD) in this study may limit their power and the generalizability of these findings.

Another influential element that could contribute to the variability of the results is the variety of tasks and stimuli used to assess processing style (Van der Hallen et al., 2015). Some of them are: the maze-map task (Caron et al., 2004), the impossible figures task (Mottron et al., 1999), the embedded figures task (Shah and Frith, 1983; Jolliffe & Baron-Cohen, 1997), the modified versions of the BDT (Wechsler, 2003, 2008) to name just a few. Individuals may use local or global processing depending on a task's requirements and the cognitive domain involved (Dukette & Stiles, 2001), and this is presumably true of individuals with ASD too. Analyzing the different results in the literature, a local bias for individuals with ASD seems to emerge in particular in tasks involving visuo-constructive abilities and sometimes in tasks assessing visuo-perceptual abilities (see Happé & Frith, 2006 for a review). Evidence in this sense has emerged, for example, with tasks that involve reconstructing a whole figure from a number of different local parts (Caron et al., 2006; Cardillo, Menazza, Mammarella, under review), or detecting visual elements embedded in larger fields (Caron et al., 2006), or discriminating between local details, patterns or gratings (Bertone et al., 2005). Conflicting findings have been reported in relation to visuospatial memory, however, with some studies highlighting a preference for the use of a local strategy (Nydén et al., 2010; Prior & Hoffmann, 1990), and others finding no impairment in visuospatial memory or enhanced local processing in individuals with ASD (Cardillo, Menazza, Mammarella, under review; Jolliffe & Baron-Cohen, 1997; Kuschner et al., 2009; Ropar & Mitchell, 2001). Different tasks, such as the same/different task (Mammarella, Giofrè, Caviola, Cornoldi, & Hamilton, 2014) spatial pattern recall (Prior & Hoffmann, 1990), the Rey-Osterrieth complex figure test or similar tasks (Cardillo, Menazza, Mammarella, under review; Jolliffe & Baron-Cohen, 1997; Kuschner et al., 2009; Ropar & Mitchell, 2001), have been used to assess visuospatial memory too, making it difficult to compare results.

Labeling individuals with ASD as "local processors", without taking the above issues into due account, is therefore simplistic. This idea needs to be reconsidered, focusing on the cognitive functioning of participants and using cross-task designs to investigate different visuospatial processing domains (D'Souza et al., 2016).

2.3 Overview of the current study[1]

The present study aimed to investigate different domains of visuospatial skills and to analyze in depth the role of global vs local processing in individuals with ASD, taking their cognitive abilities into account. Two steps were taken to avoid the above-mentioned limitations of previous research. First, participants' characteristics and their cognitive levels in particular, were clearly defined (Williams et al., 2006a). The use made in the literature of the terms ASD, HFA, and Asperger syndrome as if they were synonymous

[1] The present study has been submitted for publication: Cardillo, R., Lanfranchi, S., & Mammarella, I. C. (Submitted). A cross-task comparison on global/local visuospatial processing in Autism spectrum disorders: The role of the perceptual reasoning index.

makes it difficult to clearly define a sample's level of functioning. The individuals with ASD included in our study were all without ID and had typical verbal skills. Differently from the study of Caron and colleagues (2006) in which the visuospatial peak was calculated using only the BDT scores, in order to avoid a circular reasoning, in the present study participants were divided into two groups based on their visuospatial reasoning index (PRI) of the Wechsler Intelligence Scales (WISC or WAIS, depending on the participants' chronological age; Wechsler, 2003, 2008): one group (ASD-NP) had average scores (between 89 and 111) in the PRI; the other (ASD-P) had a visuospatial peak, i.e. a level of performance in the PRI more than one standard deviation (≥115) higher than average for the normative sample, with values between 115 and 141. By comparing these two groups with ASD with and without a visuospatial peak (ASD-P and ASD-NP) and two groups of TD individuals with and without such a peak on the PRI (TD-P and TD-NP), we expected to shed more light on any specific ASD-related deficits in the processing of visuospatial materials. The second step taken was to pay particular attention to the choice of tasks involving global-local processing across different domains of visuospatial abilities, and to use well operationalized local and global stimuli, and objective scoring methods. The paradigm of the BDT (one of the most popular tasks for investigating local vs global visuospatial processing) was used to select tasks from the literature (Caron et al., 2006), or devise new tasks ad hoc for the study. Using a solid paradigm to construct all the tasks, and exploring a wide range of visuospatial domains could help to contain the variability of the results and highlight specific effects for each domain. In particular, the chosen tasks investigated visuospatial processing speed, visuo-perceptual and visuo-constructive abilities, VSWM and their interplay with local and global processing.

We expected that both groups of participants with ASD (-P and -NP) will show a bias towards local processing compared to neurotypicals participants (Caron et al., 2006; Happé & Frith, 2006; Mottron, Burack, Iarocci, Belleville, & Enns, 2003). We also hypothesized that participants in the PRI peak group will show a larger bias towards local processing than the PRI non-peak group (Caron et al., 2006; Mottron & Burack, 2001). In addition, we expected differences in performance in the visuospatial tasks according to the various levels of PRI: better performance for the groups with a peak and performance less accurate for the groups without peak.

A mixed-effects model approach was used to test our research questions (Pinheiro & Bates, 2000). This approach is demonstrated to be effective in dealing with complex data and allows the researcher to simultaneously consider all factors that potentially contribute to the understanding of the structure of the data (Baayen, Davidson, & Bates, 2008). These factors comprise not only the standard fixed-effects variables controlled by the experimenter (in our case, perceptual coherence, condition, and group) but also the random-effects factors, in other words, factors whose levels are drawn at random from a population (in our case, participants).

2.4 Method

2.4.1 Participants

The study involved 77 participants: 39 (29 M) individuals with ASD but no ID and 38 (28 M) matched TD controls. Based on their scores on the PRI (measured with the WISC IV or WAIS IV: Wechsler, 2003, 2008, depending on their chronological age), participants were assigned to one of four groups: ASD with (ASD-P) and without (ASD-NP) a visuospatial peak and TD individuals with (TD-P) and without (TD-NP) a visuospatial peak. The groups without the peak included participants with PRI scores within one standard deviation of the average (between 85 and 111), while participants in the groups with the peak had PRI scores more than one standard deviation higher than average (between 115 and 141). The four groups were matched for chronological age [F (3, 73) = 1.21, p = .312; η^2_p = .047], and gender [χ^2 (df = 3) = .249, p = .969]. Each group with ASD (-P and -NP) was also matched with the respective TD group (-P and -NP) for PRI scores [F (1, 31) < 1 and F (1, 42) < 1 respectively]. Differences between groups emerged for the IQ scores [F (3, 73) = 31.31, p < .001; η^2_p = .56]. The ASD-NP group showed lower scores than all the other groups (p_s < .001), while the TD-P group had higher scores than all the other groups ($p_s \leq .01$). No differences emerged between the ASD-P and TD-NP groups. Finally, a main effect of Group emerged also for the vocabulary (Wechsler, 2003, 2008) subtest [F (3, 73) = 26.21, p < .001; η^2_p = .52]. Participants in the ASD-P and ASD-NP groups had lower scores than both TD-P and TD-NP groups ($p_s \leq .003$), with no differences between each other. A summary of the participants' characteristics is shown in Table 2.1.

All participants were recruited via local community contacts in northeast Italy, at specialized centers for ASD or at schools (for the TD children).

Participants in the ASD groups had all received an independent clinical diagnosis of either HFA (n = 27) or Asperger syndrome (n = 12), according to DSM-IV-TR (APA, 2000) or ICD-10 (World Health Organization, WHO, 1992) criteria. They had also scored above the threshold for ASD in the Autism Diagnostic Interview (ADI-R; Rutter Le Couteur, & Lord, 2005), showing no differences between the ASD-P and ASD-NP groups concerning each subscale: reciprocal social interaction [F (1, 37) < 1]; language/communication [F (1, 37) = 1.66, p = .21; η^2_p = .04], repetitive behaviors/interests [F (1, 37) = 1.62, p = .21; η^2_p = .04]. Children with ASD were only included in this study only if they achieved a standard score of 80 or above for full-scale

IQ with the Wechsler Intelligence Scales (WISC IV or WAIS IV: Wechsler, 2003, 2008, depending on the participants' chronological age). All participants with ASD also had scores within normal range ($\geq$7) on the Vocabulary subtest (WISC IV or WAIS IV: Wechsler, 2003, 2008, depending on the participants' chronological age) and were taking no medication (see Table 2.1).

The TD controls were healthy children of normal intelligence (Table 2.1) with no history of psychiatric, neurological and neurodevelopmental disorders, who were tested individually at school.

Table 2.1 Characteristics of Groups: ASD with (ASD-P) and without (ASD-NP) a PRI peak, typically developing individuals with (TD-P) and without (TD-NP) a PRI peak.

Measures	ASD-P (n = 17)	TD-P (n = 16)	ASD-NP (n = 22)	TD-NP (n = 22)
Gender (M:F)	12:5	12:4	17:5	16:6
Age (months)				
Mean (SD)	149.19 (34.65)	143.62 (22.20)	163.22 (42.34)	163.01 (38.96)
Range	113–251	114–190	102–238	99–247
PRI[a]				
Mean (SD)	125.88 (8.9)	124.88 (6.79)	101.05 (6.55)	101.77 (7.39)
Range	115–141	115–137	89–111	85–111
IQ [a]				
Mean (SD)	104.62 (14.64)	123.20 (8.61)	90.33 (9.45)	111.5 (11.21)
Range	80-128	115–141	80–113	91–126
Vocabulary[a]				
Mean (SD)	10.13 (2.50)	14.70 (2.03)	8.55 (2.02)	12.89 (2.69)
Range	7-16	11-18	7-13	8-19
ADI-R: A (Reciprocal Social Interaction)				
Mean (SD)	20.67 (5.45)		19.05 (6.36)	
Range	10–28		9–28	
ADI-R: B (Language/Communication)				
Mean (SD)	15.2 (4.57)		13.37 (4.86)	
Range	7–24		5–23	
ADI-R: C (Repetitive Behaviors/Interests)				
Mean (SD)	7.64 (2.6)		5.89 (3.56)	
Range	1–11		1–12	

Note. [a] Standard scores on the Wechsler Intelligence Scale for Children—Fourth Edition (for participants aged 8 to 16 years) or Wechsler Adult Intelligence Scale – Fourth Edition (for participants from 16 years onwards). PRI = Perceptual Reasoning Index; IQ = Intelligence Quotient. ADI-R = Autism Diagnostic Interview-Revised (Rutter et al., 2005); elevated scores on the ADI-R reflect greater levels of autistic symptomatology.

All participants were native Italian speakers, without visual or hearing impairments, or other neurological diagnosed conditions. Individuals with ASD who had comorbid psychopathologies were excluded. The study was approved by the research ethics committee at the University of Padova, Italy; all participants provided assent to participate in our research, and their parents signed an informed consent form.

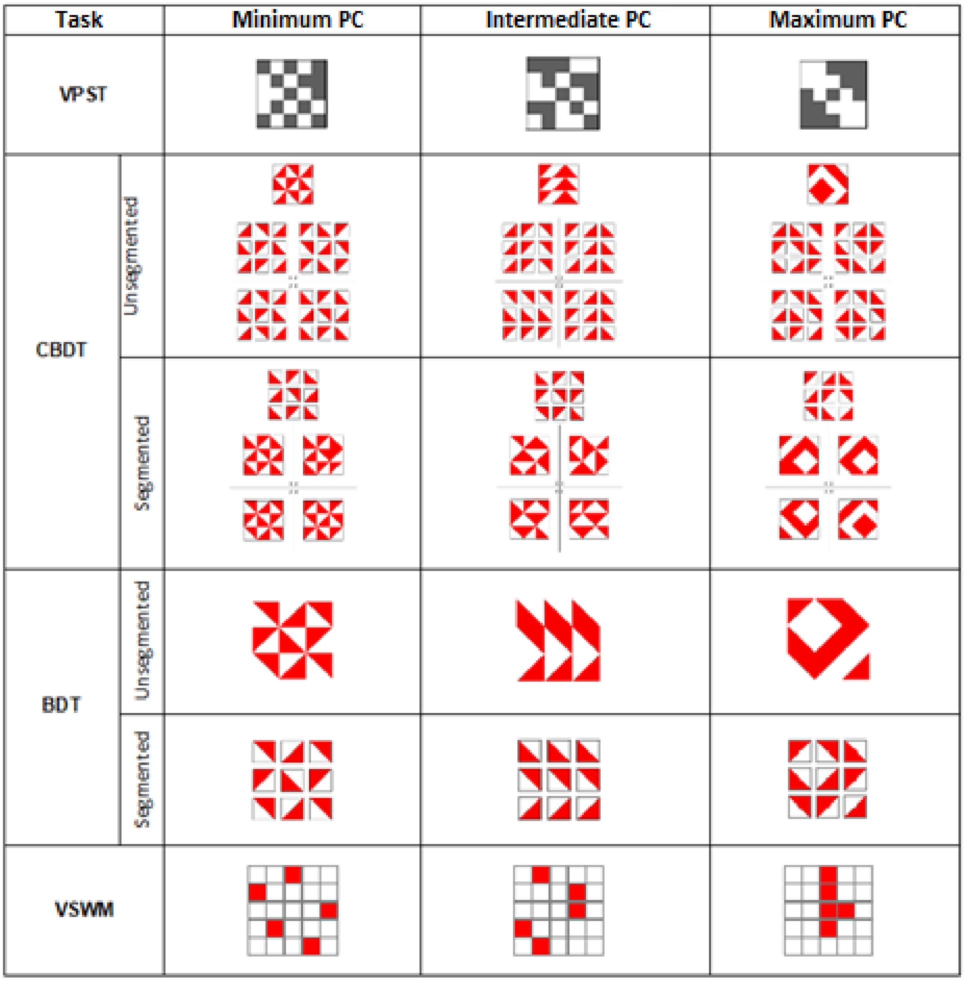
2.4.2 MATERIALS

Manipulation of global/local processing

For the all tasks, the stimuli were prepared on different levels of perceptual cohesiveness (PC), which is a global property of figures that can be manipulated by varying the number of "adjacencies" of opposite-colored edges between the blocks/cells (Caron et al., 2006). A given figure could have a minimum PC (many edge cues and adjacencies of opposite-colored blocks/cells, forming local configurations), an intermediate PC (when half of the blocks/cells comprising the figure had adjacencies with opposite-colored blocks/cells, and the other half had adjacencies with same-color blocks/cells), or a maximum PC (the blocks/cells had adjacencies with others of the same color, forming global configurations) (see Figure 2.1).

As can be seen from the Figure 2.1 when the level of PC is minimum, the elements comprising a figure are more amenable to being processed locally, focusing on the different squares; when the level of PC is maximum, the arrangement of the squares forming the figure tends to prompt their global processing.

Figure 2.1 Examples of stimuli drawn from the VPST, CBDT (unsegmented and segmented conditions), BDT (unsegmented and segmented conditions) and the VSWMT, presented for three levels of PC (minimum, intermediate and maximum).



Note: VPST: Visuospatial processing speed task; CBDT: Computerized block design task; BDT: Block Design Task; VSWMT: Visuospatial Working Memory Task; PC: Perceptual Cohesiveness.

Visuospatial processing speed task (VPST)

The VPST assessed perceptual encoding speed for meaningless visual patterns. The stimuli consisted of 5 x 5 grids, each containing 25 white and grey square cells distributed to involve different levels of PC. Participants were asked to look at the target figure on the right and then choose the corresponding figure from among four distractors as quickly as possible. The task consisted of 36 items presented in three different conditions - minimum, intermediate and maximum PC (12 for each level) - and participants had one minute to complete each condition (See Figure 2.1). For accuracy scoring, one point was awarded for each correct answer and zero for answers that were wrong or given beyond the time limit.

Computerized block design task (CBDT)

The CBDT was a modified version of a matching task derived from the study by Caron et al. (2006; see also Cardillo, Mammarella, Garcia, & Cornoldi, 2017). Our modified version comprised two conditions. The unsegmented condition involved matching an unsegmented target figure with a corresponding segmented figure presented among three segmented distractors. The segmented condition involved matching a segmented target figure with a corresponding unsegmented figure presented among three unsegmented distractors. The distractors differed from the target in terms of color inversion, local differences and target rotation. Both versions consisted of 36 trials, 12 for each level of PC (minimum, intermediate and maximum). Participants were told they would see a figure at the top of the screen (target stimulus) and they were asked to choose the figure corresponding to the target stimulus as quickly as possible from among four options presented at the bottom (See Figure 2.1). Answers were given by indicating the number corresponding to the correct response (and a score of 1 was assigned to each correct figure match). The experimenter pressed the spacebar to record response times (RTs) and then recorded the answer by pressing one of four keys on a keyboard. The accuracy of the answers and the RTs (in milliseconds) were analyzed. One point was awarded for each correct answer and zero for a wrong answer.

Modified Block Design Task (BDT)

The Modified BDT (Caron et al., 2006) assessed visuo-constructive abilities and visuospatial processing styles. Participants were shown a two-dimensional red and white geometrical pattern and then asked to reproduce it by assembling a set of blocks comprising six colored surfaces (two red, two white, two half-red and half-white). The material for this task consisted of 18 items presented in two different conditions: unsegmented and segmented. The items differed in terms of level of PC (minimum, intermediate and maximum), and were balanced in terms of the size of the pattern (4, 9, or 16 blocks). Figure 2.1 shows examples of the stimuli. For each matrix size, a control condition measuring the motor speed component involved in BDT construction was added, in which participants were required to complete as quickly and accurately as possible a monochromic square presented in both the segmented and the unsegmented condition. The task was administered according to Wechsler's instructions (WISC, Wechsler, 2003; Italian version: Orsini, Pezzuti & Picone, 2012). Participants were asked to respond as quickly and accurately as possible. A time limit was set for each block configuration, which was 75, 120 and 180 s, for the 4-, 9-, and 16-block patterns, respectively (see Cardillo, et al. 2017). Performance was timed from the moment the stimulus was placed in front of the participant up until the pattern was completed or the time limit elapsed. Following the procedure, proposed by Caron et al. (2006), the order of presentation of the trials was identical for all participants and the unsegmented condition was presented before the segmented condition to avoid a facilitation effect. The number of blocks correctly placed for each pattern was considered as a measure of accuracy, and RTs (in seconds) were also recorded[2].

[2] In order to control individual differences in motor speed, the time taken to carry out the control condition was subtracted from the response times of each item. In this way the response times were analysed by controlling for the motor speed of each participant.

Visuospatial working memory task (VSWMT)

The VSWMT is a computerized task for assessing visuospatial working memory (Cardillo et al., under revision). The task consisted of 36 items in the form of white matrixes containing increasing numbers of cells, some of which were red (span: from 4 to 9). The stimuli were balanced in terms of the level of PC (minimum, intermediate and maximum), and two items per span (from 4 to 9) were included for each level of PC. The stimuli with a high level of PC were easy to group into a global configuration and consequently prompted a global processing, whereas the figures with low level of PC were more amenable to being processed locally, by focusing on the different components (Figure 2.1).

Participants were shown a matrix for 3 s, and asked to memorize the configuration. Then, after a .5 s inter-stimulus interval, they were asked to recall the pattern on a completely blank matrix of the same size, using the mouse to mark the red cells seen previously. The order of presentation proceeded from the lower to the higher spans, while a random order was used to present the items within each span. The partial credit score was used for scoring purposes (Conway, et al. 2005; Giofrè & Mammarella, 2014), i.e., considering the proportion of cells correctly recalled on each matrix.

2.4.3 PROCEDURE

Participants were tested in a quiet room during two individual sessions lasting approximately 40 minutes each. Tasks were administered in a counterbalanced order. Instructions were given for each task, and participants practiced with each task before starting the experiment. The CBDT and the VSWMT were administered using a laptop computer with a 15-inch LCD screen, and the experimental procedure was programmed with the E-Prime 2.0 software (Schneider, Eschman, & Zuccolotto, 2007).

2.5 Results

Data analyses were conducted using R (R Core Team, 2015), using a mixed-effects modelling approach and the "lme4" package (Bates, Maechler, Bolker, & Walker, 2015). The significance of both fixed and random effects was tested through a series of likelihood ratio tests for nested models based on the chi-square distribution (Pinheiro & Bates, 2000). The Akaike Information Criterion (AIC; Akaike, 1974) was also reported for each model (a lower AIC indicates a better model).

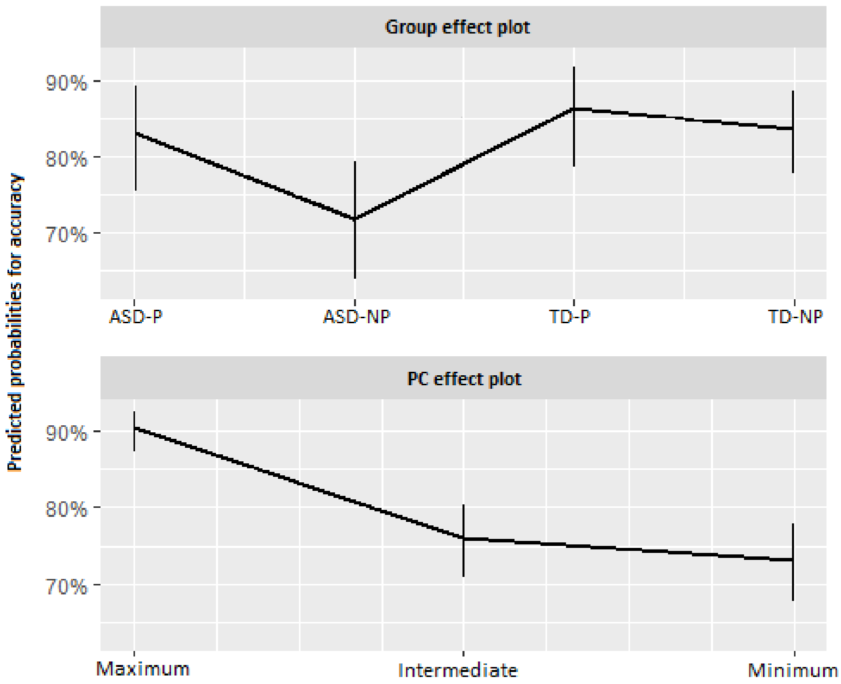
The accuracy data obtained with the VPST and VSWMT were analyzed using a logistic mixed-effects model approach (Baayen, 2008; Jaeger, 2008). Concerning accuracy in the CBDT and BDT, all groups made very few mistakes overall, resulting in a non-normal distribution of the data that precluded any statistical analysis. For this reason and consistently with a previous study (Caron et al., 2006), only the RTs were analyzed for these tasks. *RT*s for correct answers were analyzed for the CBDT and BDT adopting a generalized linear mixed approach with the function family as "Gamma" and the link as "log".

The following fixed effects and their interactions, were tested for all tasks: Group (4 levels: ASD-P, ASD-NP, TD-P, TD-NP) and level of PC (3 levels: Minimum, Intermediate, Maximum). The fixed effect of Condition (2 levels: Segmented, Unsegmented) was also considered for the CBDT and BDT. Participants were included as random effects to consider their variability in each mixed-effect model. Graphical effects were obtained using the "sjplot" package (Lüdecke & Schwemmer, 2017).

VPST- Accuracy. For accuracy in the VPST the significant effects are shown in Figure 2.2. A significant main effect emerged for the fixed effect of Group [$\chi2(3) = 8.65$,

p = .03 (full model: *AIC* = 2694.8; model without Group: AIC = 2697.4)]. The model coefficients showed that the ASD-NP group was less accurate than the other three (p_s <.04). No other differences emerged between the groups. The main effect of the Level of PC was significant too [χ2(2) = 112.38, p < .001 (model without level of PC: AIC = 2803.2)]. The model coefficients showed that the performance was more accurate with stimuli characterized by a maximum PC than for intermediate or minimum levels (ps<.001), and it was more accurate for intermediate PC than for the minimum level (p<.001). The interaction between Group and Level of PC was not significant [χ2(6) = 9.47, p = .15 (model with Interaction: AIC = 2697.3)].

Figure 2.2 Predicted probabilities for accuracy in the VPST for the principal effects (Group and Perceptual Cohesiveness). Error bars represent 95% confidence intervals.



CBDT- Response times (RTs). No main effect of Group emerged [χ2(3) = 1.16, p = .76 (full model: *AIC* = 92071; model without Group: AIC = 92066)], but the main effect of Condition was significant [*χ2*(1) = 23.13, p < .001 (model without Condition: *AIC* =

92092)]. The model coefficients showed that participants completed the task in the unsegmented condition faster than in the segmented one (p <.001). The main effect of the level of PC was significant too [$\chi 2(2) = 809.91$, $p < .001$ (model without PC: *AIC* = 92877)]. The model coefficients showed that participants completed the task faster on the maximum level of PC than on the intermediate or minimum levels ($p_s < .001$), and they were faster on the intermediate than in the minimum level ($p < .001$). The analysis also revealed the significant interaction between Group and Condition [$\chi 2(3) = 17.87$, $p < .001$ (model with Interaction: *AIC* = 92059)]. As shown in Figure 2.3, the model coefficients showed that the ASD-NP group revealed in the segmented condition slower performance than TD-P ($p = .004$), while no differences emerged with respect to the other groups. On the contrary, in the unsegmented condition the ASD-NP group showed slower performance than all the other groups ($p_s < .001$). No other significant differences emerged between groups. The interaction between Group and level of PC was significant [$\chi 2(6) = 12.70$, $p = .05$ (model with Interaction: *AIC* = 92070)]. The ASD-NP group showed slower performance than TD-P and TD-NP groups in the minimum level of PC ($p = .002$ and $p < .001$ respectively). Instead, in the intermediate level the ASD-NP group was slower only than the TD-P group ($p = .001$). Finally, in the maximum level of PC no differences emerged between groups. In addition, the interaction between level of PC and Condition was significant [$\chi 2(2) = 11.21$, $p = .004$ (model with Interaction: *AIC* = 92064)]. Only in the intermediate level of PC participants were faster in the unsegmented condition than the segmented one ($p = .002$), while no differences emerged between conditions for the other levels of PC. Finally, the interaction between Group, Condition and level of PC was no significant [$\chi 2(6) = 3.44$, $p = .75$ (model with Interaction: *AIC* = 92228)].

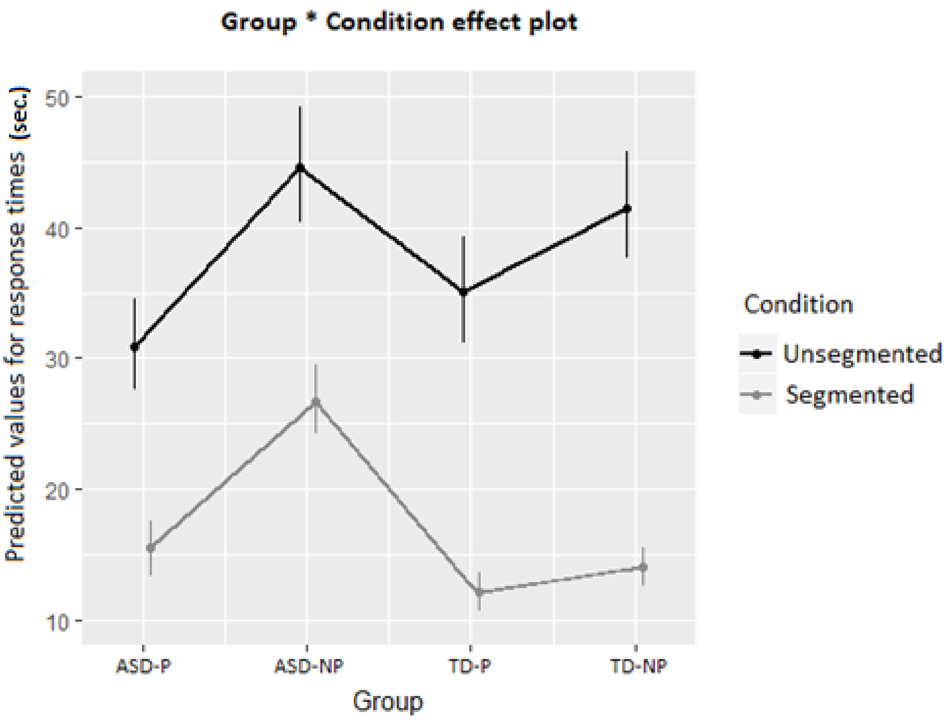
Figure 2.3 Predicted values for Response Times (*ms*.) by Group and Condition in the CBDT. Error bars represent 95% confidence intervals.

BDT - Response times (RTs). A significant main effect of Group emerged [$\chi 2(3) = 16.17$, $p = .001$ (full model: *AIC* = 23191; model without Group: AIC = 23201)]. The model coefficients showed that the ASD-NP group had slower performance than all other groups ($p_s \leq .002$), while no other differences between groups emerged.

The main effect of Condition was significant [$\chi 2(1) = 597.84$, $p < .001$ (model without Condition: *AIC* = 23787)]. The model coefficients showed that participants completed the task in the unsegmented condition more slowly than in the segmented one ($p < .001$). The main effect of the level of PC was significant too [$\chi 2(2) = 70.28$, $p < .001$ (model without PC: *AIC* = 23257)]. The model coefficients showed that participants completed the task faster on the minimum PC level than on the intermediate or maximum levels ($p_s < .001$), and they were faster on the intermediate than on the maximum level of PC ($p < .001$). As shown in Figure 2.4 the analysis revealed a significant interaction between Group and Condition, [$\chi 2(3) = 48.57$, $p < .001$ (model with Interaction: *AIC* =

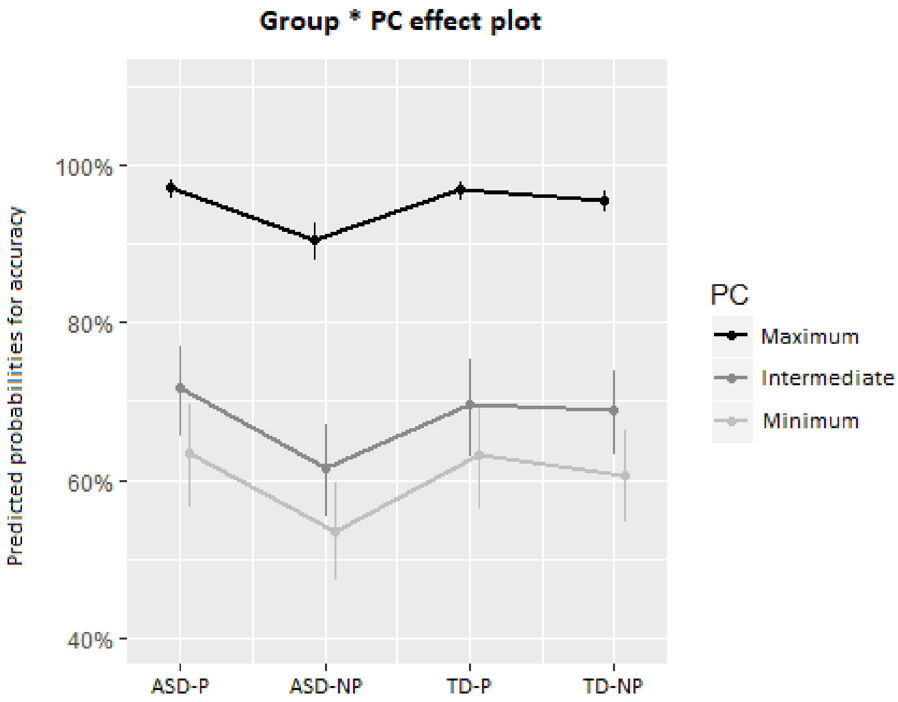
23148)]. The model coefficients showed that in the unsegmented version the ASD-P group was faster than all other groups (p_s<.001) and the ASD-NP group was the slower (p_s<.01). Instead, in the segmented condition the ASD-NP group had slower performance than all other groups (p_s<.001). The interaction between Condition and level of PC was significant too [$\chi 2(2) = 83.00$, $p < .001$ (model with Interaction: *AIC* = 23112)]. The model coefficients showed that in the unsegmented version participants had faster performance on the minimum level of PC than on the intermediate or maximum levels (p_s<.001), and on the intermediate than in the maximum level ($p < .001$). No such differences emerged between the levels of PC in the segmented condition. Finally, the interaction between Group and Level of PC was not significant [$\chi 2(6) = 8.81$, $p = .18$ (model with Interaction: *AIC* = 23194)]. Similarly, the interaction between Group, Condition and Level of PC was not significant [$\chi 2(6) = 8.70$, $p = .19$ (model with Interaction: *AIC* = 23082)].

Figure 2.4 Predicted values for Response Times (*sec.*) by Group and Condition in the BDT. Error bars represent 95% confidence intervals.



VSWMT – Accuracy. A significant main effect of Group was found [*χ2*(3) = 9.91, *p* = .02 (full model: AIC = 8256.2; model without Group: *AIC* = 8260.1)]. The model coefficients showed that the ASD-NP group was less accurate than all other groups (p_s <.03). No other differences emerged between the groups. There was a main effect of PC [*χ2*(2) = 2580.6, *p* < .001 (model without PC: *AIC* = 10832.8)]. The model coefficients showed that participants recalled stimuli better if they were characterized by a maximum PC than when the levels of PC were intermediate or minimum (p_s<.001), and their recall was better for intermediate than for minimum PC levels (*p*<.001). As shown in Figure 2.5, the analysis revealed a significant interaction between Group and Level of PC as well [*χ2*(6) = 35.866, *p* < .001 (model with Interaction: *AIC* = 8232.4)].

Figure 2.5 Predicted probabilities for Accuracy by group and Perceptual Cohesiveness (PC) in the VSWMT. Error bars represent 95% confidence intervals.



The model coefficients showed that both TD groups (-P and -NP) and the ASD-P group performed better than the ASD-NP group on the maximum and intermediate levels of PC (ps<.02 and ps<.04, respectively). In tasks with a minimum PC, however, only the ASD-P (p =.04) and TD-P (p = .05) groups proved more accurate than the ASD-NP group, which did not differ from the TD-NP group. No other significant differences emerged.

2.6 Discussion

The main aim of the present study was to investigate visuospatial abilities and to analyze in depth the role of global-local processing across different tasks, in participants with ASD but no ID compared with a TD group.

As mentioned previously, several studies and interesting theories have sought to clarify global-local processing in individuals with ASD, often with conflicting results that have added to uncertainty over the topic (Van der Hallen et al., 2015). A methodological issue that may contribute to this situation concerns the cognitive levels of the samples involved, which often varied considerably or were not clearly characterized (e.g. Alloway, Rajendran, & Archibald, 2009; Brosnan, Gwilliam, & Walker, 2012; Koshino, et al., 2005; Ropar & Mitchell, 2001). To overcome this limitation, our study was conducted on two groups of participants with ASD, without ID, and with typical verbal skills: the ASD-NP group had average scores on the PRI (Wechsler, 2003, 2008), while the ASD-P group had a visuospatial peak. These groups were compared with two corresponding TD groups (TD-NP and TD-P) matched for age, gender and PRI. Previous studies had used different tasks and stimuli (with different requirements and involving different cognitive domains) to assess the processing style of individuals with ASD (Van der Hallen et al., 2015). A preference for local or global processing may vary from one task to another, however (depending on the visuospatial domains involved [Dukette & Stiles, 2001]), so using different tasks can easily generate mixed findings. Tasks based on the BDT paradigm (Wechsler, 2003, 2008) were therefore used in our study to investigate visuospatial processing speed, and visuo-perceptual, visuo-constructive and VSWM. For all tasks, the influence of local/global processing on participants' performance was analyzed by manipulation the PC of the stimuli.

Our results in the VPST assessing visuospatial processing speed revealed that the ASD-NP group was less accurate than the other groups, showing impaired visuospatial processing speed skills, while ASD-P group did not differ from the TD controls. As concerns global-local processing, all groups performed better in this task with stimuli presenting global rather than local configurations. This goes to show that, in the VPST, it was easier for all participants, with or without ASD, to recognize and promptly discriminate between configurations when a global processing of the stimuli was required, whereas the need for a local processing makes it more difficult for them to complete the task quickly. This result is consistent with the global precedence hypothesis formulated by Navon (1977). Previous studies using various tasks reported mixed findings for individuals with ASD, whose processing speed was sometimes lower (Mayes, & Calhoun, 2007; Oliveras-Rentas, Kenworthy, Roberson, Martin, & Wallace, 2012), sometimes higher (Scheuffgen, Happé, Anderson, & Frith 2000) than in controls. Wallace and colleagues (Wallace, Anderson, & Happé, 2009) found them much the same as in controls, even after splitting their sample into two IQ subgroups (IQ < 100 and IQ $\geq$ 100). It may be that the small number of children with a lower IQ in both the ASD and the TD groups prevented them from detecting any significant differences (Wallace et al., 2009), and this might explain the discrepancy with our results.

As for visuo-perceptual abilities, assessed with the CBDT, the only difference emerging between the groups concerned the ASD-NP group's slower performance in the unsegmented, but not in the segmented condition. This finding argues in favor of individuals with ASD-NP having difficulty with the visual integration process, and is in line with previous reports of a limited capacity for spatial integration in individuals with ASD (Booth, Charlton, Hughes, & Happé, 2003; Jolliffe & Baron-Cohen, 2001; Nakano, Ota, Kato, & Kitazawa, 2010; Shalev, 2007). Previous research suggested that integrating local information in a visual task is more challenging for individuals with ASD, and their degree of difficulty correlates with the severity of their ASD symptoms (Olu-Lafe, Liederman, & Tager-Flusberg, 2014). Bearing in mind that more severe ASD symptoms can be associated with a lower IQ (Mayes, & Calhoun, 2011), this may explain why the ASD-NP group - but not the ASD-P group – were found weaker in this ability in our study.

On the other hand, the influence of the level of PC of the stimuli was clearly apparent in the CBDT, in line with the global precedence hypothesis (Navon, 1977). All four groups' performance was faster when global configurations were presented (maximum PC) and slower when the figures were composed of local details (minimum PC). The ASD-NP group had the greatest difficulty integrating local information to obtain a coherent whole, completing the task more slowly than either TD group (-P and -NP) on the minimum level of PC, whereas their performance did not differ from that of the other groups on the maximum level of PC.

Visuo-constructive abilities were tested with the modified BDT, in which the ASD-P group completed the task more quickly than all the other groups in the unsegmented (global presentation) condition, as seen in other studies (Caron et al., 2006; Happè & Frith, 2006). Importantly, segmenting a gestalt seemed to be less effortful for the ASD-P group than for the others because of their diminished sensitivity to perceptual coherence and to their more locally-oriented processing of visuospatial material (Caron et al., 2006; Shah & Frith, 1993). This finding is consistent with several previous studies that produced evidence of a local bias in ASD (see Happé & Frith, 2006 for a review). In the segmented (local presentation) condition, the ASD-NP group was again slower than all the others.

While the literature provides robust evidence of the local bias associated with ASD in the visuo-constructive domain, mixed findings have been reported regarding a global processing weakness in this setting (Happé & Frith, 2006). Our groups with ASD seemed to have intact global processing skills, on a par with the TD groups. The main picture emerging from our results thus points to the ASD-P having a clear preference for local processing in the visuo-constructive task, and no deficit in process global configurations seemed to emerge to both groups with ASD (-P and -NP) in this task.

As for the VSWMT, no deficits emerged for the ASD-P group on comparing them with the TD controls, whereas the ASD-NP group had a worse performance than all the others in recalling figures with the maximum PC. For the intermediate and minimum PC, however, there was no longer any difference between the ASD-NP and the TD-NP groups, which both performed less well than the groups with higher PRI scores (TD-P and ASD-P). Our results suggest that VSWM is not a major weakness in the cognitive domain of individuals with ASD (Alloway et al., 2009; Geurts, Verte, Oosterlaan, Roeyers, & Sergeant, 2004; Happé, Booth, Charlton, & Hughes, 2006; Ozonoff & Strayer, 2001; Sinzig, Morsch, Bruning, Schmidt, & Lehmkuhl, 2008; Williams, Goldstein, & Minshew, 2006b). It can be seen as a minor weakness for the ASD-NP group when global configurations have to been recalled. This group seemed to benefit less from the global presentation of the stimuli than the other groups, revealing a diminished sensitivity to perceptual coherence (Caron et al., 2006; Shah & Frith, 1993).

To sum up, our ASD-NP group was generally slower to respond and/or less accurate in its answers than the other groups in all the domains examined. This group revealed weaker spatial integration abilities in the visuo-perceptual domain, and a diminished sensitivity to perceptual coherence in the VSWM domain. Conversely, the ASD-P group was able to use both global and local processing styles effectively, modulating their use to suit the task in hand. It was only in the visuo-constructive domain that this group adopted a locally-oriented processing. The ASD-P group seemed to be supported by a high cognitive potential in visuo-perceptual reasoning, which enabled it to overcome the tendency for local processing. In conclusion, for both the ASD groups an intact global processing emerged with the sole exception of the ASD-NP group in the visuo-perceptual and VSWM domains.

Further studies are needed to confirm and extend these results and to overcome some limitations of the present study. It would be interesting to compare individuals with ASD with participants with different neurodevelopmental disorder to highlight any cross-disorder similarities or differences in the global-local visuospatial processing.

In our view the present study is a successful attempt to shed light on important issues related to the global-local visuospatial processing in ASD. Our results highlight the importance of examining different visuospatial processes taking into account the level of perceptual reasoning of participants with ASD. In addition, the utility of using well-operazionalized tasks inspired by the BDT (a consolidated paradigm for investigating global and local visuospatial processing) was confirmed. Considering these factors will help us to clarify the visuospatial profile of individuals with ASD. Our findings support the convinction that the use of a local or global processing style can vary depending on the requirements of the task in hand and the cognitive domain involved (Dukette & Stiles, 2001). This applies to individuals with ASD, so simply labelling them as “local processors” is not good enough. This idea needs to be revised in the light of their cognitive functioning, investigated using cross-task study designs.

CHAPTER 3

STUDY II

GLOBAL-LOCAL VISUOSPATIAL PROCESSING IN CHILDREN WITH NLD

3.1 INTRODUCTION

After investigating in depth, in the previous chapter, the issue of global-local visuospatial processing in ASD, the present chapter will focus on another neurodevelopmental disorder characterized by atypical visuospatial processing, albeit with different features: the Nonverbal Learning Disability (NLD). NLD is a disorder characterized by a persistent deficit in one or more measures of visuospatial intelligence in presence of an average or above average verbal intelligence (Cornoldi et al., 2016). Actually, this disorder has not been included in either the DSM-5 (American Psychiatric Association, APA, 2013) or the ICD-10 (World Health Organization, WHO, 1992), although this subgroup seems to have specific, clinically important characteristics that warrant careful investigation (Cornoldi et al, 2016).

The present chapter will first describe the NLD profile, paying particular attention to the definition and the main clinical features. Secondly, the second Study of the present dissertation will be presented, which aimed to investigate global-local visuospatial processing in children with symptoms of NLD. In particular visuo-constructive and visuo-perceptual abilities were explored using the modified block design (BDT) paradigm (Caron et al., 2006). It has been decided to compare the performance of children with symptoms of NLD with those of children with symptoms of dyslexia, a learning disorder presenting a different profile compared with NLD, and with typically-developing (TD) controls. Participants were presented with a modified block design task (BDT), in both a typical visuo-constructive version that involves reconstructing figures from blocks, and a perceptual version in which respondents must rapidly match unfragmented figures with a corresponding fragmented target figure. The figures used in the tasks were devised by manipulating two variables: the perceptual cohesiveness (PC) and the task uncertainty (TU), stimulating global or local processes.

3.2 Nonverbal Learning Disability: definition and main features

NLD can be considered a neurodevelopmental disorder characterized by deficits in the visuospatial (i.e., non-verbal) area, such as visuospatial and visuo-constructive difficulties (Semrud-Clikeman et al., 2010), fine motor coordination impairments, and poor mathematics achievement (Mammarella et al. 2013a), associated with well-developed language skills (Rourke & Tsatsanis, 2000). Even if this condition is typically described as NLD, different definitions have been used over the years, such as nonverbal disorder of learning (Myklebust, 1975), visuospatial learning disability (Cornoldi, Venneri, Marconato, Molin, & Montinari, 2003) and right hemisphere developmental learning disability (Tranel, Hall, Olson, & Tranel, 1987).

The first description of NLD proposed by Johnson and Myklebust (1967; Myklebust, 1975) depicted the profile of children with visuospatial difficulties showing impairments in learning or encoding through pictures, processing of gestures or motor patterns, and spatial orientation. In addition, deficits in social perception and in the regulation of attention were described.

Later, Rourke (1989; 1995) proposed a model of NLD in which interpreted this condition as a "syndrome" and distinguished deficits grouped into three main areas: neuropsychological, academic, and social-emotional/adaptational. The author also highlighted that the pattern of deficits in children with NLD appeared to change over time with changing demands at school and at home (Mammarella & Cornoldi, 2014). However, in his following studies (Pelleiter, Ahmad, & Rourke, 2001; Rourke, 2005), Rourke used the term nonverbal syndrome as an "umbrella" under which different pathologies or disorders could be included creating some critical concern about the existence of this disorder (see for example Pennington, 2009). Despite this skepticism, there has been a remarkable effort among researchers to identify a group of children who struggle with visuospatial, academic problems and possible associated social problems in the past recent years (Fine, Semrud-Clikeman, Bledsoe, & Musielak, 2013). This led to the recent proposal of a set of inclusion and exclusion diagnostic criteria (reported below), in order to find a consensus for a share diagnosis of this disorder (Cornoldi et al., 2016):

A. A persistent deficit in one or more measures of visuospatial intelligence in presence of an average or above average verbal intelligence.
B. Substantial weaknesses, currently or emerging from the child's history, in at least two of the following: (i) in perceiving or analyzing organized forms; (ii) in reproducing simple drawings by copy or memory; (iii) in temporarily remembering and manipulating visuospatial information.
C. Presence of clinical and/or psychometric indexes of weaknesses, currently or emerging from the child's history, in at least one of the following areas:
    1. Fine-motor impairments (e.g. in the use of hands for drawing or handwriting; in using zips or button-fastening);

2. Poor academic achievement in activities involving visuospatial abilities, such as mathematics, in presence of an average or above average performance in reading decoding;
3. Difficulties in social interaction (e.g. verbose speaking, difficulties in understanding nonverbal communication, difficulties in interpreting facial expressions).

D. Several symptoms were present before the age of 7 years although they could have not become fully manifest until academic demands exceeded children's capacities.
E. Clear evidence that the symptoms interfere with academic or social functioning.
F. These difficulties are not better explained by the presence of Autism Spectrum Disorders (ASD) or Developmental Coordination Disorder (DCD). The diagnosis of NLD can be given in presence of soft symptoms of ASD, or DCD, but if the criteria for those disorders are met the diagnosis of NLD does not apply. Similarly if the NLD profile seems a consequence of a condition of intellectual disability, sensory disabilities, neurological and/or genetic conditions, the diagnosis of NLD is not applied.

3.2.1 Visuo-constructive and visuo-perceptual skills in NLD

Although a crucial aspect of the NLD profile relates to poor visuospatial abilities, the visuo-constructive and visuo-perceptual skills of children with this condition have been less explored than other abilities such as visuospatial working memory (e.g., Mammarella & Cornoldi, 2005). Available evidence suggests that children with NLD may be impaired in tasks involving visuo-constructive skills, requiring the reconstruction of fragments belonging to an entire integrated figure (Cornoldi et al., 2016). In particular, children with

NLD have often showed difficulties with tasks involving part-to-whole construction, like the Object Assembly subtest of the WISC scale (e.g. Drummond, Ahmad, & Rourke, 2005). In addition, a similar difficulty was reported comparing the performance of children with NLD and with TD in simple tasks requiring the organization of three to four puzzle pieces and involving visuospatial working memory (Cornoldi, dalla Vecchia, & Tressoldi, 1995). These difficulties with visuo-construction may be also related to low performance in different tasks, such as praxic tasks, motor coordination, oculo-motor integration, perception, and memory of organized visual patterns (Cornoldi et al., 2016). Previous research revealed that children with NLD obtained low performances in the Rey-Osterrieth complex figure test (Gross-Tsur, Shalev, Manor, & Amil, 1995; Semrud-Clikeman, et al. 2010), and in the Visual-Motor Integration Test (Mammarella et al., 2006; Roman, 1998; Semrud-Clikeman, et al. 2010), requiring to copy and/or retrieving and drawing images from memory, and showed for both tasks lower performance than children with Asperger Syndrome or ADHD (Semrud-Clikeman et al., 2010).

Concerning visuo-perceptual abilities, Rourke (1989, 1995) hypothesized a neuropsychological deficit in the visual perception of children with NLD when it came to discriminating between and recognizing visual details and relationships, but no objective data were reported. In particular, according to Rourke (1995), simple visual discrimination could reach normal levels over the years, but other perceptual deficits can persist. In fact, several studies shown significant impairments in NLD related to complex visual-spatial-organizational skills (Cornoldi et al., 2016). For example, Roman (1998) described a single case of a child with NLD with specific perceptual difficulty concerning spatial feature, performing poorly in the Benton Judgment of Line Orientation test (Benton, Hamsher, Varney, & Spreen, 1983). Semrud-Clikeman et al. (2010) reported similar findings in a group of children with NLD compared with Asperger Syndrome or

ADHD using the same task, and Chow and Skuy (1999) showed that children with NLD performed less well than children with specific language disorders on gestalt configuration tasks. Finally, Mammarella and Pazzaglia (2010) found that children at risk of NLD performed worse than controls in visual perception tasks that entailed comparing visual stimuli and locations in space (without involving memory), and in reversing an ambiguous figure.

Finally, it is interesting to note that despite there is no evidence of deficit involving visual acuity in NLD, it seems that specific sensory processes may be weaker. For example, poor performance in tasks assessing stereopsis (the ability to have fully binocular vision for depth perception and three-dimensional visualization) were reported for children with NLD, providing a possible explanation of why these children show particular difficulty in processing three-dimensional stimuli (Cornoldi et al., 2016).

3.3 Overview of the current study[3]

In the present research, we aimed to investigate the effect of PC and TU by comparing children with symptoms of NLD with children with symptoms of dyslexia or with TD children.

Children with developmental dyslexia are characterized by problems with accurate or fluent decoding, and weak spelling abilities (DSM5, APA, 2013). Deficits involving the verbal abilities (including phonological processing) have been extensively described in children with dyslexia (Ackerman & Dykman, 1993; Gould & Glencross, 1990; Helland & Asbjørnsen, 2004; Palmer, 2000), while there are conflicting findings on these children's performance in visuospatial tasks (Garcia, Mammarella, Tripodi &

[3] The present study has been published: Cardillo, R., Mammarella, I. C., Garcia, R. B., & Cornoldi, C. (2017). Local and global processing in block design tasks in children with dyslexia or nonverbal learning disability. *Research in Developmental Disabilities, 64*, 96-107. doi:10.1016/j.ridd.2017.03.011

Cornoldi, 2014). Previous studies found higher (Swanson, 1984; von Károlyi, 2001), lower (Benton, 1984; Menghini, Finzi, Carlesimo & Vicari, 2011; Morris et al., 1998; Winner et al., 2001), or comparable visuospatial abilities of individuals with dyslexia with those of controls (Jeffries & Everatt, 2004; Siegel & Ryan, 1989; Sinatra, 1988; Winner et al., 2001). It has also been reported, however, that children with dyslexia may have deficits in visual attention tasks (Bosse, Tainturier, & Valdois, 2007; Heiervang, & Hugdahl, 2003), or difficulties in tasks that measure processing speed, such as the WISC Coding and Symbol Search (Kail, Hall & Caskey, 1999), which involve visual stimuli; and their weakness becomes particularly evident when response times are considered (see also Cornoldi, Giofré, Orsini, & Pezzuti, 2014; Shanahan et al., 2006). To date, few studies have distinguished explicitly between the global and local characteristics of a perceptual stimulus in children with dyslexia (e.g. Keen & Lovegrove, 2000), and none have explored these perceptual characteristics in cases of NLD, despite this distinction proving crucial when examining the perceptual difficulties associated with other related developmental disabilities (e.g. Happé, 1999), and despite evidence to suggest that it could be relevant in the case of NLD as well (Chow & Skuy, 1999).

In the present Study, children were presented with two slightly-modified versions of the BDT used by Caron et al. (2006), assessing visuo-constructive and perceptual skills by using configurations with high or low levels of cohesiveness and TU, respectively. In the visuo-constructive BDT, the children had to reproduce a configuration using the appropriate sides of a set of cubes. In this task, configurations with a low PC can be processed locally; it is easy to examine the various parts, so participants can use a local-by-local strategy to match each part of the figure with the surfaces of the single blocks. This strategy enables the task to be completed more accurately and more rapidly (than if a global strategy is adopted) (Caron et al., 2006; Royer, Gilmore, & Gruhn, 1984). In contrast, a global-by-local strategy is needed in high PC conditions because the configurations are processed globally and respondents must mentally divide the figure into blocks, understand the relationships between them, and then match each part of the figure to one of the sides of the blocks. In addition, the level of TU of the stimuli affects the tasks complexity, introducing a higher number of details in the condition of maximum TU than in the minimal. The perceptual version of the task involves matching an overall configuration with the same configuration (among several distractors), which may be perceived globally even though it is fragmented (see Figure 3.1), and this allows for a global-by-global strategy to be rapidly implemented, especially in the case of high PC figures.

Specifically, we aimed to analyze whether: 1) PC and TU affect performance in visuo-constructive and perceptual BDT; 2) children with symptoms of NLD or dyslexia have weaknesses in these two tasks; and 3) PC and TU affect them differently. In other words, we compared the performance of children with symptoms of NLD, dyslexia, or TD in the two tasks, examining whether they had difficulties in the visuo-constructive and perceptual versions of the task. In addition, we explored whether they performed better when the blocks were combined with others to form global or local configurations and if the increasing number of details affects their performance. Concerning the effects of PC, we expected (in the light of previous research, e.g. Caron et al., 2006) that, by favoring global processing, a high level of PC would impair performance in the visuo-constructive task, in which the cubes needed to be processed locally, adding pieces one at a time. A high level of PC may improve performance in the perceptual task, however, where the global configuration can still be perceived even when the single pieces are presented fragmented. Concerning the effects of TU, we expected that the higher number of details characteristic of the stimuli with maximum TU would impair the performance in both the visuo-constructive and perceptual task. In contrast, figures with minimal TU, presenting a lower level of complexity than the maximum condition, may be processed more easily. Concerning the comparison between the groups, in agreement with previous findings (Mammarella & Cornoldi, 2014; Semrud-Clikeman, et al. 2010) we expected children with symptoms of NLD to have a particular difficulty in the visuo-constructive task, but not necessarily in the perceptual task. On the other hand, bearing in mind the previously-mentioned conflicting findings regarding the visuospatial deficits of children with dyslexia, we were unable to predict their performance in either the visuo-constructive or the perceptual BDT. Finally, as concerns the comparison between local and global processing, we predicted that children with symptoms of NLD would be less able to adapt their visual processes to the characteristics of the stimulus (Cornoldi et al., 2016). In particular, the group with symptoms of NLD was expected to have a particular difficulty in manipulating the highly cohesive configuration in the visuo-constructive task in order to cope with the need for fragmentation imposed by the task. Children with symptoms of NLD were also expected to be more disadvantaged than the other groups from using configurations with maximum TU in both visuo-constructive and perceptual tasks.

A mixed-effects model approach was used to test our research questions (Pinheiro & Bates, 2000). This approach is demonstrated to be effective in dealing with complex data and allows the researcher to simultaneously consider all factors that potentially contribute to the understanding of the structure of the data (Baayen, Davidson, & Bates, 2008). These factors comprise not only the standard fixed-effects variables controlled by the experimenter (in our case, perceptual coherence, condition, and group) but also the random-effects factors, in other words, factors whose levels are drawn at random from a population (in our case, participants).

3.4 Method

3.4.1 Participants

The initial screening involved a sample of 282 children (147 M, 135 F) aged 8 to 11 years (*M* = 112.49 months; *SD* = 8.69). The children's socioeconomic level was estimated by their teachers on a 4-point scale (1 = high; 2 = medium-high; 3 = medium-low; 4 = very low). Twenty-one children were immediately excluded from this initial sample because: 16 had a diagnosis of intellectual disability or special educational needs; 3 had only recently moved to Italy and did not speak Italian fluently; and 2 were judged to belong to families with a low socioeconomic level.

The children were tested in two sessions. In the first, they were administered the Verbal Meaning (VM), and Spatial Relations (SR) subtests of the Primary Mental Ability (PMA) test battery (Thurstone & Thurstone, 1963), and the Lexical Decision Task (LDT) (Caldarola, Perini, & Cornoldi, 2012). The VM subtest measures verbal skills and vocabulary, and comprises 30 trials in which participants are given a target word and asked to choose which of four options has the same meaning as the target. The SR subtest measures visuospatial reasoning skills and consists of 25 trials in which participants are shown an incomplete geometrical shape and asked to choose one of four options that completes the shape. One point was assigned for each correct answer. In the LDT, participants are presented with a list of pseudo-words and high-frequency words (60 of each) and asked to find as many pseudo-words as they can.

For the VM and SR subtests, mean values were calculated on our sample as a whole (due to the old standardization of the battery), whereas normative values were used for the LDT. The sample's mean score was 23.0 (*SD* = 6.2) for the VM subtest, and 11.63 (*SD* = 4.38) for the SR subtest.

The initial criteria for including a child in the Group with symptoms of NLD were: (a) scores lower than the 20^{th} percentile in the SR subtest of the PMA; (b) average scores in the VM subtest of the PMA, the LDT and the word reading task. In our sample, 48 children obtained scores below the 20^{th} percentile in the SR subtest, but 22 of them also obtained scores below the 20^{th} percentile in the VM subtest or the LDT and were excluded for this reason, giving us a total of 26 possible children belonging to the Group with NLD.

The initial criteria for including a child in the group with symptoms of dyslexia were: (a) scores lower than the 20^{th} percentile in the VM subtest of the PMA (Thurstone & Thurstone, 1963) and the LDT; and (b) average scores in the SR subtest of the PMA. In our sample, 36 children obtained scores below the 20^{th} percentile in the VM subtest and LDT, and 9 of them also obtained scores below the 20^{th} percentile in the SR subtest, giving us a total of 27 possible children belonging to the group with dyslexia.

The initial inclusion criteria for the TD group were: (a) average scores in the VM subtest of the PMA, the LDT and the word reading task; and (b) average scores in the SR subtest of the PMA. In our sample, 152 children obtained average scores in all the above-mentioned tasks, and from these we randomly allocated 27 children to the TD group to obtain a comparable number of participants in each group.

In the second session, visuo-constructive abilities were tested with Rey's Complex Figure test (Rey, 1968): the children were asked to copy and then recall a complex drawing. Reading decoding (in terms of time and accuracy) was also tested using a word reading task (DDE-2; Sartori, Job, & Tressoldi, 2007) consisting of 112 lexical items to be read aloud as quickly and accurately as possible. Based on these latter tasks, 6 children in the group with symptoms of NLD, and 7 in the group with symptoms of dyslexia did not confirm their weaknesses in visuo-constructive and reading decoding tasks, respectively, and 7 children in the TD obtained scores below the 20^{th} percentile in the visuo-constructive or reading tasks (4 for Rey's Complex Figure test, 3 for the word reading task). Our final sample thus consisted of 60 children: 20 with symptoms of NLD (9 M, 11 F; mean age = 111.19 months; *SD* = 7.01), 20 with symptoms of dyslexia (12 M, 8 F; mean age = 109.93 months; *SD* = 7.21), and 20 TD controls (9 M, 11 F; mean age = 111.99 months; *SD* = 6.04). The groups did not differ significantly in terms of age, $F(2, 57) = .48$, $p = .63$, or gender distribution, $\chi^2(df = 2) = 1.18$, $p = .55$. From here on, the terms children with NLD, children with dyslexia, and TD children refer to these three groups.

All the children spoke Italian as their first language, and none had any visual or hearing impairments. None of the participants had any clinical diagnoses or neurological conditions. A signed informed consent form was obtained from participants' parents and the study was conducted in accordance with the ethical criteria established by the Italian Scientific Society (AIP, 2015) and in accordance with the Declaration of Helsinki.

Table 3.1 summarizes the children's descriptive statistics by group (NLD, dyslexia, and TD), the results of the group comparisons based on one-way ANOVAs, and the effect sizes for all pairwise comparisons.

3.4.2 Materials and Procedure

Participants were tested during an individual session lasting approximately 1 hour, in a quiet room outside the classroom. The children were presented with the modified block design task and the 'reverse' (perceptual) computerized block design task derived from Caron et al. (2006). A pilot study run on a random sample of TD children attending primary school, ensured that the level of difficulty of the tasks was appropriate. The instructions for each task were presented and each task was practiced before starting the experiment. The computer-based task was administered using a laptop computer with a 15-inch LCD screen, and the experimental procedure was programmed with the E-Prime software (Schneider, Eschman, & Zuccolotto, 2007). The child sat in front of the computer screen, and the experimenter sat on the child's right to present the trial and manage the keyboard. Participants were asked to give their answers aloud, and the experimenter input their answers using the keyboard.

As in the previous work by Caron et al. (2006), figures were prepared with low or high levels of PC (the global property of a figure that enables it to be manipulated by varying the number of "adjacencies" of opposite colored edges between blocks). For the low level of PC, the sides of the blocks composing the figures were always adjacent to blocks of different color, forming local configurations; for the high level of PC, the blocks always had adjacencies with others of the same color, forming global configurations (see Figure 3.1). Task uncertainty (TU) and matrix size were also controlled when constructing the figures and classifying the difficulty of each item. TU (Caron et al., 2006) corresponds to the number of decisions potentially needed to copy a figure: for each block, it may be 1 if the block's side has only one color, or 2 if it has two colors, in which case the block has to be oriented correctly. The sum of the TUs for each block comprising the target figure gives a measure of the total TU involved in the figure's construction (for more details, see Caron et al., 2006). Matrix size refers to the number of blocks comprising the figure (4, 9 or 16).

Modified block design task (BDT)

The material consisted of 12 items, 6 with a high and 6 with a low PC. The two sets of items (with a low and a high PC) were identical in terms of TU (50% minimal, 50% maximum), and matrix size (two items for each of the configurations, containing 4, 9, or 16 blocks).

Table 3.1 Mean (*M*) scores in the screening tasks, with standard deviations (*SD*), results of group comparisons based on one-way ANOVAs, and effect sizes (Cohen's *d*) for all pairwise comparisons.

Screening tasks	**TD** (n = 20)		**Dysl** (n = 20)		**NLD** (n = 20)		One-way ANOVAs					
							TD/Dysl		**TD/NLD**		**Dysl/NLD**	
	M (*SD*)	Min – Max	*M* (*SD*)	Min – Max	*M* (*SD*)	Min – Max	*p*	Cohen's *d*	*p*	Cohen's *d*	*p*	Cohen's *d*
PMA spatial	12.15 (1.31)	[10.00 – 14.00]	12.15 (2.54)	[9.00 – 18.00]	5.7 (1.38)	[2.00 – 7.00]	1	0.00	<.001	4.70	<.001	3.09
PMA verbal	25.65 (3.38)	[17.00 – 29.00]	15.05 (4.29)	[7.00 – 20.00]	24.75 (4.09)	[18.00 – 30.00]	<.001	2.69	.453	0.24	<.001	2.27
Lexical decision task	33.2 (8.39)	[25.00 – 54.00]	17.2 (4.25)	[8.00 – 25.00]	32.6 (10.47)	[21.00 – 59.00]	<.001	2.36	.843	0.06	<.001	1.89
Word reading time [*z* scores]	-.56 (.55)	[-1.23 - 0.74]	1.31 (1.81)	[0.77 – 5.35]	-.49 (.65)	[-1.52 - 0.53]	<.001	1.37	.714	0.12	<.001	1.30
Rey's copy	26.73 (5.5)	[13.50 – 35.00]	25.58 (5.27)	[15.50 – 33.00]	20.43 (6.3)	[3.00 – 27.00]	.504	0.21	.002	1.04	.008	0.87
Rey's recall	14.15 (4.7)	[7.00 - 23.50]	15.7 (5.24)	[8.50 – 28.00]	10.08 (4.14)	[4.00 – 16.00]	.331	0.31	.006	0.90	.001	1.17

Note: TD: typically- developing group; *Dysl:* group with dyslexia; *NLD:* group with nonverbal learning disability.

With the exception of word reading times (for which z scores were computed), for the other measures raw scores are reported.

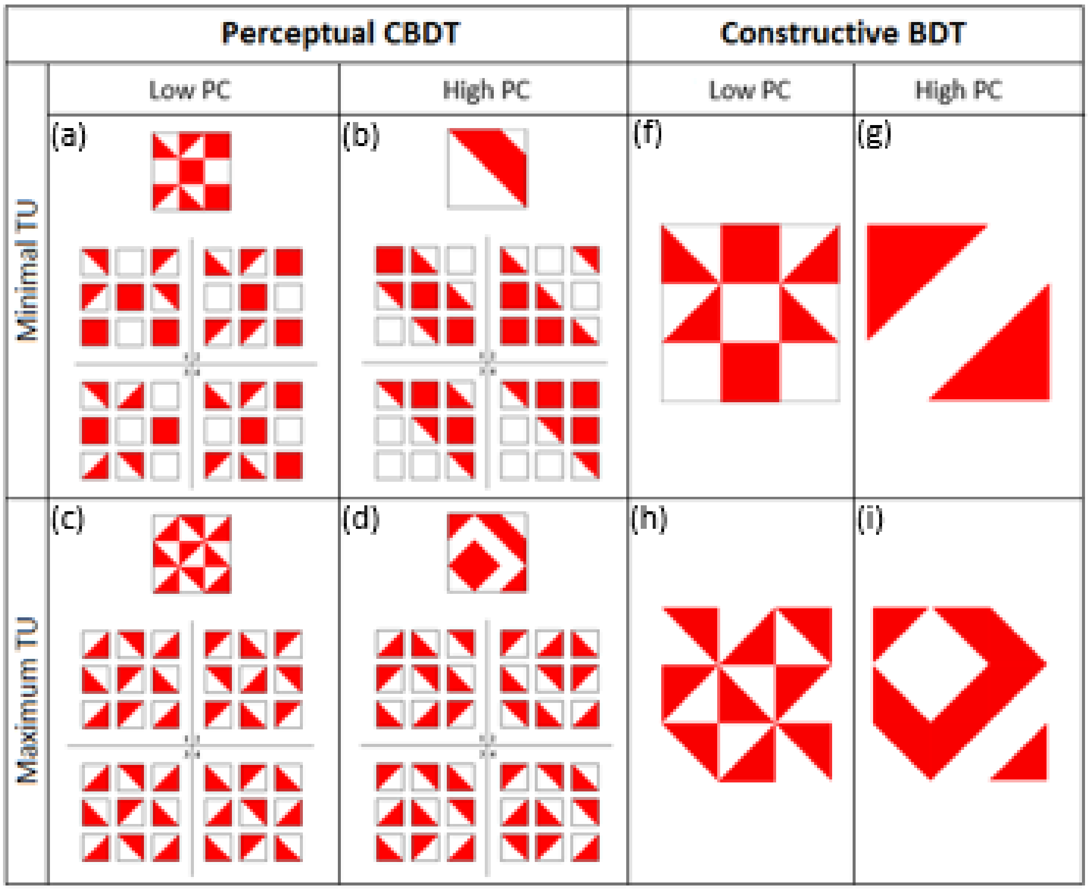
The task procedure followed Wechsler's instructions (WISC, Wechsler, 2003). First, the children were shown the blocks (with two red, two white and two bicolored sides) and the book of stimuli showing the figures to construct. Then two examples were used for familiarization purposes, the first completed by the experimenter, the second by the participant. If the child had fully understood the task, the 12 items were presented. Figure 3.1 shows examples of the stimuli for both low and high levels of PC and minimal and maximum TU. The children were instructed to respond as quickly and accurately as possible. A time limit was set for each block configuration. In particular, based on the pilot study, the initial cut-off proposed by Caron et al. (2006) was reduced, and the time limits for the 4-, 9- and 16-block designs were 75, 120 and 180 s, respectively.

The number of blocks correctly placed on each design was considered. Following the procedure proposed by Caron et al. (2006), the order of presentation of the trials was identical for all participants. The trials were arranged by level of TU (from lower to higher) within each size of matrix (comprising 4, 9, and 16 blocks), and, within each TU level, by level of PC (low to high).

'Reverse' (perceptual) computerized block design task (CBDT)

The CBDT was a matching task derived from the study by Caron et al. (2006). The task involved matching an unfragmented figure as quickly as possible with a corresponding fragmented target figure presented among three fragmented distractors. The distractors differed from the target in terms of color inversion, local differences, and rotation. Examples of these stimuli are shown in Figure 3.1 for low and high levels of PC and minimal and maximum TU.

Figure 3.1 Examples of stimuli used. On the left panel figures drawn from the Perceptual CBDT task are presented, with the following characteristics, respectively (a) low perceptual cohesiveness (PC) and minimal Task Uncertainty (TU), (b) high PC and minimal TU, (c) low PC and maximum TU, (d) high PC and maximum TU. On the right are presented figures drawn from the Constructive BDT task, with (f) low PC and minimal TU, (g) high PC and minimal TU, (h) low PC and maximum TU, (i) high PC and maximum TU.



The task consisted of 24 trials (12 with a high and 12 with a low level of PC) structured in the same way as the Modified BDT. Participants were told that they would see a figure at the top of the screen (target stimulus) and they were asked to choose the figure corresponding to the target stimulus as quickly as possible from among four fragmented options presented at the bottom. Answers were given by verbally indicating the number corresponding to the correct response (and a score of 1 was assigned to each correct figure match). The experimenter pressed the spacebar to record response times (RT) and then recorded the answer by pressing one of four keys on a keyboard.

3.5 RESULTS

Data analyses

Regarding accuracy, data analyses were conducted using R (R Core Team, 2015) and were performed on 720 data points for the BDT, and 1440 data points for the CBDT.

The accuracy data (obtained from the answers given by participants during the BDT and CBDT) were modeled using generalized mixed-effects modelling methods, and run using the "lme4" package (Bates et al., 2015). Binomial responses were analyzed using logistic mixed-effects models (Baayen, 2008; Jaeger, 2008). Graphical effects were obtained using the "effects" package (Fox, 2003).

For both tasks, the fixed effects tested were Group (with 3 levels: TD, Dyslexia and NLD), level of PC (Low, High), TU (minimal, maximum) and their interaction. Participants were included as random effects to take into account their variability in each model.

We adopted a model selection strategy for all the dependent variables examined (see for example Fox, 2008), following the same procedure to detect the best-fitting model. First, starting from the null model (M0 - i.e., the model that only included the random factor, acting as a baseline), we built the various models by adding one effect at a time, so all the possible models were fitted. Then the models were compared using the Akaike Information Criterion (AIC, Akaike, 1974) as a fit index (following the procedure suggested by Burnham, Anderson, & Huyvaert, 2011), the best model showing the smallest AIC value. For the visuo-constructive BDT, generalized mixed-effect models were run, choosing the "Poisson family", whereas the "binomial family" was used for the perceptual CBDT.

Reaction times (RTs) for correct answers (measured in seconds) were analyzed for the CBDT. The data were skewed and violated the distribution requirement of the ANOVA, so they were submitted to a logarithmic transformation as recommended by Winer (1971). Then a mixed analysis of variance (ANOVA) was run with group as the between-subjects factor and level of PC and TU as the within-subject factor, and post-hoc analyses were performed using Bonferroni's correction.

Measures of effect size were also computed for the BDT and CBDT, for both accuracy and response times, recording Cohen's *d,* which expresses the effect size of the pairwise comparisons between the factors considered.

Accuracy modelling

Starting from the initial model (null model), different subsequent models were fitted by adding one factor at a time, beginning with the additive effects, followed by the relevant interactions. Thus, the factors considered in the present study were added to the initial models in the order: Group, level of PC and TU. Then the interactions between the factors were included. Mixed-effect models were fitted on the data with all the listed factors as fixed effects, while participants were included as crossed random effects.

The best model(s) were selected from the set of models tested by applying information-theoretic (I-T) approaches, by considering the *AIC* (Akaike Information Criterion) and the relative likelihood (l) of each model (Burnham et al., 2011). For each model I, *AICs,* Δ^0_{AICs} $[\Delta^0_{AIC} = AIC_{null} - AIC_i]$, Δ_{AICs} $[\Delta_{AIC} = AIC_{best\ model} - AIC_i]$, and ls $[l = \exp(\Delta_{AIC}/2)]$ were computed: Δ^0_{AIC} greater than 0 meant that a particular model *i* fitted the data better than the null model; Δ_{AIC} described the distance between the best model and the other models computed; *l* values greater than 1 indicated a higher plausibility of the model considered. Details of the modelling process and the indexes that guided model selection are given in Table 3.2.

Table 3.2 Model comparison for accuracy in BDT and CBDT: Akaike Information Criterion; $\Delta^0 AIC$ = *AIC* difference with respect to null model (M0); *ΔAIC* = *AIC* difference and *l* = relative likelihood with respect to best target model (i.e. *exp*(*ΔAIC*/2)); the higher the *ΔAIC*, the better the model.

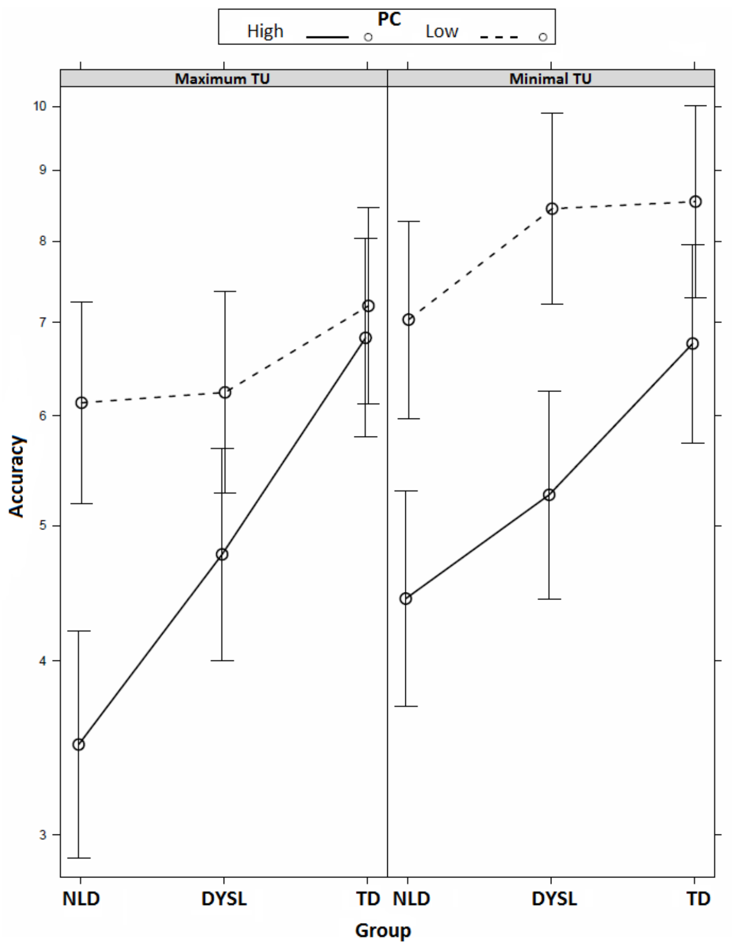
	AIC	$\Delta°_{AIC}$	Δ_{AIC}	*l*	Model
BDT					
M0	4902.1	0	-176.6	<.001	(Participants)
M1	4896.6	5.5	-171.1	<.001	Group + (Participants)
M2	4776.3	125.8	-50.8	<.001	Group + PC level + (Participants)
M3	4749.7	152.4	-24.2	<.001	Group + PC level + TU + (Participants)
M4	4727.7	174.4	-2.2	.33	Group * PC level + TU + (Participants)
M5	4749.9	152.2	-24.4	<.001	Group * TU + PC level + (Participants)
M6	4747.8	154.3	-22.3	<.001	Group + PC level * TU + (Participants)
M7	**4725.5**	**176.6**	**0**	**1**	**Group * PC level * TU + (Participants)**
CBDT					
M0	1190.5	0	-30.7	<.001	(Participants)
M1	1192.3	1.8	-32.5	<.001	Group + (Participants)
M2	1170.4	20.1	-10.6	.005	Group + PC level + (Participants)
M3	**1159.8**	**30.7**	**0**	**1**	**Group + PC level + TU + (Participants)**
M4	1159.9	30.6	-0.1	.951	Group * PC level + TU + (Participants)
M5	1162.5	28	-2.7	.259	Group * TU + PC level + (Participants)
M6	1161.1	19.4	-1.3	.522	Group + PC level * TU + (Participants)
M7	1167.2	23.3	-7.4	.024	Group * PC level * TU + (Participants)

Note: Group: TD, Dyslexia, NLD; *PC level*: low or high.

Final model accuracy

Visuo-constructive Block Design Task (BDT). Following the above procedure, as shown in Table 3.2, our model-fit analysis of accuracy showed that the best-fitting model was *m7* Group * PC level * TU+ (Participants), represented in Figure 3.2. The interaction Group x PC level x TU revealed differences between groups only for the high level of PC. In this condition, the global presentation of the stimuli requires a more local approach, compared to the low level of PC, to perform correctly the task. Moreover, children with NLD performed less well than the TD group for both minimal (*Cohen's d* = 0.51) and maximum levels of TU (*Cohen's d* = 0.68). Instead the group with dyslexia differed significantly from the TD group only for the maximum level of TU (*Cohen's d* = 0.39), showing lower performances when the stimuli were characterized by a higher number of local details (colored edge cues).

Figure 3.2 Principal effects of the best model for accuracy in the BDT: Group * PC level * TU + (Participants). Error bars represent 95% confidence intervals.

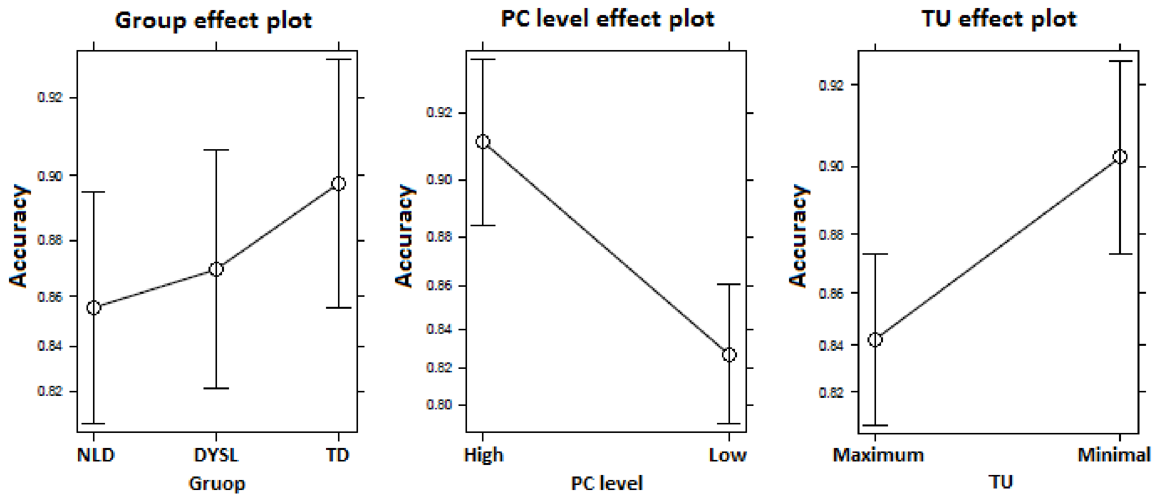


Furthermore, observing the differences between high and low PC in relation to the TU of the stimuli different patterns for each group emerged: children with NLD showed better performances in the low than in the high PC level for both minimal

(*Cohen's d* = 0.62) and maximum TU (*Cohen's d* = 0.61). Differently, children with dyslexia showed a better performance in the low than in the high PC level (*Cohen's d* = 0.69) for the minimal level of TU, while no differences emerged between the PC levels when the TU was maximum (*Cohen's d* = 0.31). Finally, TD children did not show differences between high and low PC for both conditions of TU (*Cohen's d* = 0.36 for minimal TU and *Cohen's d* = 0.08 for maximum TU).

Perceptual Computerized Block Design Task (CBDT) - Accuracy. As shown in Table 3.2, the model-fit analysis of accuracy indicated that the best-fitting model was *m3* Group + PC level + TU+ (Participants), represented in Figure 3.3. In fact, introducing the subsequent interactions did not make a significant difference compared with the model that included only the main effects (*m3*), nor did its lead to an improvement in the AIC index.

Figure 3.3 Principal effects of the best model for accuracy in the CBDT: Group + PC level + TU + (Participants). Error bars represent 95% confidence intervals.



As shown in Figure 3.3, the three groups had a similar overall performance and the main effect of group was not significant. A main effect of the level PC was found, however, underscoring the PC-related differences: participants performed better when the level of PC was high than when it was low (*Cohen's d* = .26). In addition, a main effect of TU emerged, showing that participants had a lower performance in the maximum than in the minimal TU condition (*Cohen's d* = .18).

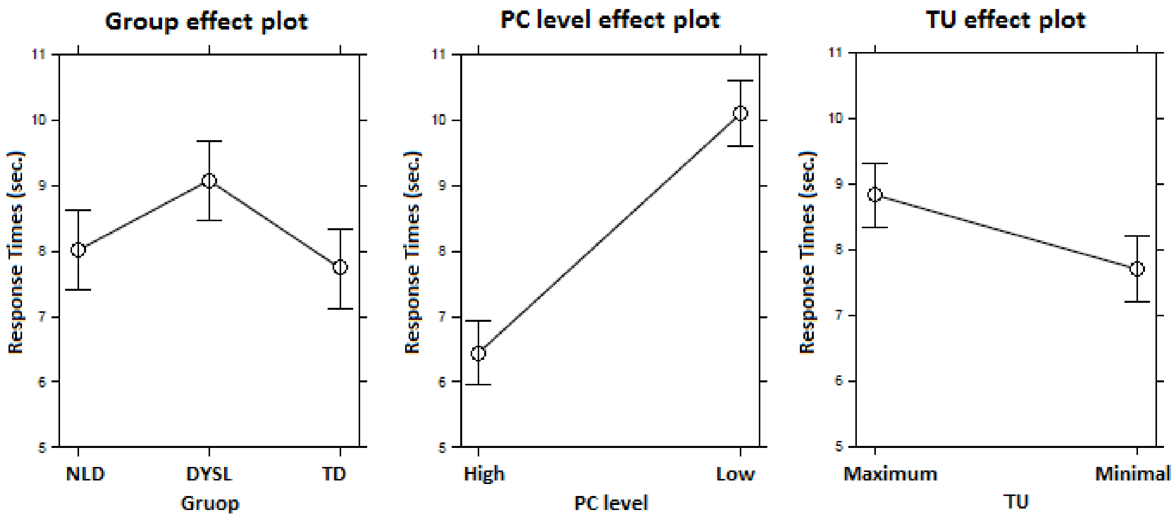
Computerized Block Design Task (CBDT) - Response times. As previously mentioned, response times were analyzed by applying a logarithmic transformation. In Figure 3.4, the data are not transformed, however, to make the results easy to understand at first glance. The mean response times of the three groups show that the group with dyslexia was generally slower than the other two groups. Here again, PC and TU affected participants' performance.

The main effect of group emerged, $F(2, 57) = 6.73$, $p = .001$, meaning that the reaction times of the group with dyslexia were slower than those of the TD group ($p = .013$, *Cohen's d* = .44), while the group with NLD did not differ significantly from the group with dyslexia ($p = .13$, *Cohen's d* = .32) or the TD group ($p = 1$, *Cohen's d* = .13). The main effect of the level of PC, $F(1, 57) = 126.62$, $p<.001$, was significant: all participants completed tasks with the high level of PC faster than the low level of PC ($p < .001$, *Cohen's d* = 1.40). Also the main effect of TU, $F(1, 57) = 7.93$, $p = .005$, was significant: participants completed tasks with a minimal TU faster than when the TU was maximum ($p = .02$, *Cohen's d* = .29).

None of the subsequent interactions was significant: PC level x group [$F(2, 57) < 1$], TU x group [$F(2, 57) < 1$], PC level x TU [$F(1, 57) < 1$] and Group x PC level x TU [$F(2, 57) < 1$]. Nevertheless, it is worth noting that the group with NLD (*Cohen's d* = .47) showed a greater difference in response times between the two conditions of

TU than the groups with TD (*Cohen's d* = .14) or Dyslexia (*Cohen's d* = .27), revealing a greater slowdown in the maximum than in the minimal TU condition.

Figure 3.4 Principal effects for response times in the CBDT (in seconds): Group + PC level + TU + (Participants). Error bars represent 95% confidence intervals.



3.6 Discussion

Research on specific learning disorders has paid little attention to visuospatial abilities, and particularly to the implications of local and global processing requirements, which seem to play a crucial part in some neurodevelopmental disorders, such as ASD (Happé, 1999; Caron et al., 2006), Williams syndrome (Farran et al., 2003), or Down syndrome (Bellugi et al., 2000). The overall aim of the present study was to investigate local and global visuospatial processing, on both perceptual and visuo-constructive levels, in children aged from 8 to 11 years with symptoms of NLD or dyslexia. In particular, we aimed to analyze whether these two groups of children perform better when global or local configurations are present in visuo-constructive or perceptual tasks, in the same way as TD children, by comparing the effects of the level of PC and TU in two modified versions of the block design task proposed by Caron et al. (2006).

To the best of our knowledge, few studies published to date have compared the neuropsychological functioning of children with dyslexia and NLD in visuo-constructive and perception tasks. In particular, the effects of PC and global or local processing styles have never been studied in such children, though they have been explored in depth in cases of ASD (e.g., Happé, 1999; Caron et al., 2006), and individuals with genetic syndromes (e.g., Farran et al., 2003; Bellugi et al., 2000).

Our first objective was to test whether PC and TU affect performance in visuo-constructive and perceptual BDT tasks. Our results, based on generalized mixed-effects models, indicate that participants were more accurate for configurations in the visuo-constructive task (BDT) with a low as opposed to a high PC level. This finding is in agreement with previous research (Caron et al., 2006), and confirms that in visuo-constructive tasks, it is easier to arrange blocks to represent configurations when a local processing of the stimuli is demanded. Instead, a global processing makes more difficult to complete the local analysis of the stimuli needed to reproduce the configuration, as suggested by Navon (1977). In perceptual tasks, on the other hand, we found performance better for a high than for a low level of PC because the former makes it easier to compare the global target configuration with the global configuration emerging from the fragmented pattern. In addition, for both visuo-constructive and perceptual tasks our results highlighted the effect of TU, confirming that participants struggle to solve the tasks with maximum than with minimal TU. Therefore, a higher number of local elements makes the task more complex, reducing the accuracy and increasing the response times.

Our second and third aims were to examine whether children with NLD or dyslexia would be weaker than TD children in the two tasks, and whether they would be affected differently by the levels of PC and TU. Differences did, in fact, emerge. In the visuo-constructive task, participants with NLD performed less well than children with TD for both TU conditions, but only for the stimuli demanding a global processing (*Cohen's d* = .51 for minimal TU and *Cohen's d* = .68 for maximum TU), not when local processing was required. Also the children with dyslexia differed significantly from the TD group for the stimuli demanding a global processing, but only when the complexity of the task and the number of local elements were higher (*Cohen's d* = 0.39 for maximum TU). These results suggest that our children with NLD and Dyslexia had no particular difficulty when the task proposed configurations with a low level of PC that favored a local analysis of the stimuli. Our children with NLD or dyslexia encounter more problems than TD children when asked to reconstruct global configurations with high levels of PC, a condition in which it becomes necessary to analyze the picture and identify the relationships between its components in order to complete the task correctly. Specifically, children with NLD obtained worse performance than the other groups, showing lower accuracy in both TU conditions. On the contrary, the performance of children with Dyslexia seem to be slightly impaired, showing a worse performance than TD only in the maximum level of task complexity. It should be noted that, unlike the children with HFA studied by Caron et al. (2006), our children with NLD showed no superiority in the BDT with a high level of PC. This result reveals a distinction between ASD and NLD - in contrast with the tendency of some authors to associate the two syndromes (Klin, Volkmar, Sparrow, Cichetti, & Rourke, 1995; Rourke et al., 2002). This indirect comparison has only a speculative value for the time being. Further studies are needed to compare these two groups directly, using the same tasks. Importantly, our results are consistent with previous research indicating that the reconstruction of a complex figure may be particularly difficult for children with NLD, possibly reflecting problems with planning, organization, and visuospatial reasoning, as well as with visual motor skills (Semrud-Clikeman et al., 2010). Our findings highlighted also a slight difficulty in children with Dyslexia on the visuo-constructive task, in agreement with previous findings showing a lower performance of this clinical group (or of a subgroup of children with dyslexia) in visuospatial tasks (Morris et al., 1998; Winner et al., 2001).

Unlike the case of the visuo-constructive task, in the perceptual version of the task (CBDT) all participants performed better with global (high PC) than with local (low PC) configurations and with a lower (minimal TU) than with a higher (maximum TU) number of details, in terms of both accuracy and response times. Global configurations were recognized faster, and were easier to distinguish than local configurations, and this global advantage was seen in all three groups, as suggested by the global dominance hypothesis (Navon, 1977). When we looked at the response times in the perceptual task, however, we observed that children with dyslexia were slower than TD children. This result is consistent with a previous study by Keen and Lovegrove (2000), in which individuals with dyslexia had no problem with processing global and local configurations, but they did prove slower than the control group in processing visual stimuli. It is also in line with previous findings obtained using visual stimuli in which children with dyslexia seemed to be particularly slow (Cornoldi et al., 2014; Heiervang, & Hugdahl, 2003). More in general, our results are consistent with those of Shanahan et al. (2006), who suggested that children with dyslexia have a processing speed deficit. Concerning the perceptual task, it is also worth noting that children with NLD performed clearly worse than the other groups when a greater number of local elements was introduced, showing a substantial slowdown in response times (*Cohen's d* = .47 for NLD, *Cohen's d* = .14 for TD, *Cohen's d* = .27 for Dyslexia). This result warrants further, more systematic investigation, but gives the impression that - despite their overall perceptual efficiency - children with NLD are less reactive to stimuli with high complexity.

To sum up, our results confirm the importance of examining visuospatial processes in learning-disabled children, and the utility of the different versions of the BDT in distinguishing between global and local processing modalities. In fact, we found children with NLD less accurate in visuo-constructive tasks and children with dyslexia only slightly impaired in visuo-constructive task, but clearly slower in perceptual task. Our manipulation devised to compare global and local configurations affected the performance of the three groups of children tested, crucially showing that children with NLD were less able to benefit from different levels of cohesiveness and to deal with different levels of complexity, probably as a consequence of their less flexible and efficient visuospatial processes (Cornoldi et al., 2016). In particular, the global dominance mechanism (Navon, 1977) made it more complicated for the group with NLD to switch from a global to a local processing of the stimuli, as needed to complete the visuo-constructive task correctly.

Further studies are needed to confirm and extend these results, however, and to overcome the limitations of the present study. One such limitation lies in our having selected the children with NLD and dyslexia at school, not on the strength of a clinical diagnosis. In addition, although the present study contributes towards a better understanding of the specific profile of children with NLD, the ambiguities in the literature surrounding the diagnosis of NLD could mean that our group with NLD is not perfectly comparable with other groups with NLD (see Mammarella & Cornoldi, 2014). Other limitations concern the small number of tasks that we were allowed to administer, and the size of our sample of children. Further research should generalize the present results to other tasks and conditions, and involve a larger number of participants.

Despite the above-mentioned limitations, in our view the present study is a first, successful attempt to shed light on several issues that have yet to be adequately studied, such as visuo-constructive and visual perceptual impairments in children with NLD and dyslexia, and their underlying local and global cognitive processing mechanisms. Our results not only provide new information on the characteristics of these children, but may also help us to better understand their difficulties in tasks that involve the visuospatial processing of information.

CHAPTER 4

STUDY III

A CROSS-DISORDER COMPARISON ON GLOBAL-LOCAL VISUOSPATIAL PROCESSING IN ASD, NLD AND ADHD

4.1 INTRODUCTION

As seen in the previous chapters both Autism Spectrum Disorders (ASD) without intellectual disability (ID) and Nonverbal Learning Disability (NLD) may present peculiarities and/or difficulties in processing visuospatial stimuli, along with a constellation of other symptoms that makes sometimes challenging to differentiate between them (Semrud-Clikeman, Fine, & Bledsoe, 2014). In addition, both ASD without ID and NLD may show attentional difficulties (Leyfer et al., 2006; Semrud-Clikeman, 2007). After investigating the issue of global vs. local visuospatial processing separately for ASD without ID and for NLD, the present chapter will draw a cross-disorder comparison of participants' local-global visuospatial processing, highlighting similarities and differences across three clinical profiles, i.e. ASD without ID, NLD and Attention Deficit Hyperactivity Disorder (ADHD).

Similarities and differences between the clinical groups considered will be first described. Secondly, Study III of the present dissertation will be presented, which aimed to investigate visuospatial processing in children with ASD without ID, NLD, ADHD by comparing their performances with TD controls. In particular visuospatial processing speed, visuo-perceptual, visuo-constructive abilities and VSWM and their interplay with local and global processing will be examined using a battery of tasks specifically devised.

4.2 Overlaps and differences among ASD, NLD and ADHD

The description of the main characteristics of ASD and NLD reported in the previous chapters revealed how these disorders are characterized by overlaps in behavioral presentations creating a challenge for their diagnosis (Williams, Goldstein, Kojkowski, & Minshew, 2008). In particular, the ASD profile often confused with NLD is the Asperger Syndrome (DSM-IV TR, American Psychiatric Association, APA, 2000) or the High Functioning Autism (DSM-5, APA, 2013), which will be henceforth defined in this chapter how ASD without ID. Individuals with this profile demonstrate the impaired social reciprocity and atypical interests and activities seen in ASD, but show no delays in their early language development (Khouzam, El-Gabalawi, Pirwani, & Priest, 2004). The symptomatic proximity between ASD without ID and NLD is particularly expressed through impairments in motor coordination, in interpersonal awkwardness (Cornoldi, et al. 2016; Frith, 1989; Rourke, 1989; Nydén et al., 2010; Volkmar & Klin, 2000), in pragmatic language difficulties, characterized by deficits in comprehension of nonverbal social cues (e.g. facial expression, gaze, gesture, and body language; Landa Klin, Volkmar, Sparrow, 2000; Rourke & Tsatsanis, 2000; Ryburn, Anderson, & Wales, 2009; Semrud-Clikeman & Glass, 2008). Therefore, discerning between ASD without ID and NLD is not always easy (Williams et al., 2008). However, it is important to point out that the social impairments above reported are more severe in ASD without ID than in NLD and in this latter disorder the restrictive patterns of interest, typical of ASD, are absent (Semrud-Clikeman et al., 2010).

An interesting aspect to consider is the relation of both ASD without ID and NLD to attentional difficulties. Specifically, studies reported a high co-occurrence of ADHD in children with ASD (Gadow, DeVincent, & Pomeroy, 2006; Leyfer et al., 2006) with rates of comorbidity within the range of 14–78% (Gargaro, Rinehart, Bradshaw, Tonge, & Sheppard, 2011). Moreover, ADHD has been shown to be the second most common comorbid disorder in individuals diagnosed with ASD (Simonoff et al., 2008). The presence of attentional problems is also reported in children with NLD, with particular reference to inattention symptoms (Semrud-Clikeman, 2007). However, is worth noting that children with NLD may fail in visual sustained attention tasks, but they often perform well on verbal attention tasks. On the contrary, children with ADHD have difficulties in maintaining attention both to verbal and visual stimuli (Cornoldi et al., 2016). Previous studies suggested that these social and attentional difficulties in NLD are secondary to difficulties in visual-spatial development and visual perceptual problems (Rourke, 2000).

Considering visuospatial skills, the results of Study I of the present dissertation, suggested that children with ASD without ID may present heterogeneous profiles, showing higher, lower or comparable performance with those of TD controls, depending on their perceptual reasoning abilities. A minority of children with ASD without ID may show higher verbal and lower visuospatial intelligence, but unlike children with NLD who, by definition, present marked deficit in visuospatial intelligence and visuo-constructive abilities, this feature is not consistent in ASD. Hence children with NLD are expected to perform more poorly in visuospatial tasks (Semrud-Clickeman, et al., 2010). Difficulties in visuospatial abilities also occurred in children with ADHD. Previous studies highlighted visuospatial working memory and visual attention deficits in children with this disorder (Martinussen et al. 2005; Vance et al. 2007; Willcutt, Doyle, Nigg, Faraone, & Pennington 2005), while other studies showed average scores in measures of visuospatial intelligence or mental rotation abilities (Semrud-Clickeman, et al., 2010; Vance et al., 2007).

Despite the importance of differentiating between these disorders and the related clinical and educational implications, only few studies have investigated the differences between them, focusing on their neuropsychological profiles and in particular on their visuospatial abilities. Ryburn and colleagues (2009) have investigated children with ASD without ID with a battery of neuropsychological tests sensitive to NLD, comparing indirectly these two disorders and examining possible similarities in their profiles. Results showed that children with ASD without ID did not get low scores on spatial or problem-solving tasks, as NLD children, but their showed similar psychosocial difficulties, in line with NLD symptoms. Also Semrud-Clikeman et al. (2010) explored neuropsychological differences between ASD, NLD, ADHD and TD controls. The comparison between these groups on measures of visual-spatial, fluid reasoning, and motor skills showed that NLD group had particular difficulty on these domains compared to the other groups. However, only few studies have compared the visuospatial functioning of children across these diagnoses (e.g. Ryburn et al., 2009; Semrud-Clickeman, et al., 2010, 2014) and, to the best of our knowledge, no studies have investigated a wide range of visuospatial abilities such as visuospatial processing speed, visuo-perceptual, visuo-constructive abilities and VSWM and their interplay with global local processing.

4.3 Overview of the current study

The present study aimed to understand the role of visuospatial abilities in the neuropsychological profile of three neurodevelopmental disorders, through the investigation of different domains of visuospatial skills. Specifically, the performance of children with ASD without ID and NLD were compared in visuospatial processing speed, visuo-perceptual, visuo-constructive abilities and VSWM domains. In addition, in attempt to control for attentional problems frequently found both in children with ASD without ID and NLD, their performance were compared not only to a TD group but also to a group of children with ADHD. Given that some studies involving samples with ASD illustrated the importance of cross-syndrome comparisons about global vs local visuospatial processing (e.g. D'Souza et al., 2016), the interplay between visuospatial abilities and local vs global processing was investigated. In order to explore the visuospatial processes above reported, four tasks (the same of those used in the Study 1) adapted from the Block Design Task (BDT; subtest from Wechsler scales) and inspired by the study of Caron and colleagues (2006) were used with different levels of Perceptual Cohesiveness (PC).

Specifically, our aims were to: 1) Highlighting possible similarities and differences among the three clinical groups (ASD without ID, NLD and ADHD) and the TD group according to the four visuospatial domains examined: visuospatial processing speed, visuo-perceptual, visuo-constructive abilities and VSWM; 2) Highlighting strengths and weaknesses of each clinical group (ASD without ID, NLD and ADHD) by comparing their performances on the four visuospatial domains examined with the TD group; 3) Analyzing the role of global and local processing styles, exploring whether the level of PC of the stimuli may differently affect groups' performance.

In agreement with previous studies (Caron, et al. 2006), and based on the results of Study 1 we expected a bias towards local processing for the ASD group compared to TD participants only in the visuoconstructive task. Children with NLD were expected to perform less well than the other groups in all the visuospatial domains examined (Mammarella & Cornoldi, 2014; Semrud-Clickeman, et al., 2010) for both global and local stimuli. Finally, participants with ADHD were expected to show difficulties in visuospatial working memory and visual processing speed tasks (Martinussen et al. 2005; Weigard & Huang-Pollock, 2017). The comparison among ASD without ID, NLD and ADHD groups, using a wide range of visuospatial tasks, could allow us to better explore overlaps and differences between these disorders in relation to a domain not deepen investigated yet, that of visuospatial abilities. The implications of our findings in differentiating the neuropsychological profiles of these disorders have been also considered.

A mixed-effects model approach was used to test our research questions (Pinheiro & Bates, 2000). This approach is demonstrated to be effective in dealing with complex data and allows the researcher to simultaneously consider all factors that potentially contribute to the understanding of the structure of the data (Baayen, Davidson, & Bates, 2008). These factors comprise not only the standard fixed-effects variables controlled by the experimenter (in our case, perceptual coherence, condition and group) but also the random-effects factors, in other words, factors whose levels are drawn at random from a population (in our case, participants).

4.4 Method

4.4.1 Participants

The sample included 193 participants, 157 males and 36 females. Four groups of children were identified for the purpose of this study: ASD without ID (N = 46), NLD (N = 21), ADHD (N = 31) and TD controls (N = 95). The four groups were matched for chronological age [F (3, 189) = 2.34, p = .08; η^2_p = .04] with age ranging between 8 and 18 years, and gender [χ^2 (df = 3) = 4.67, p = .20]. Only children who achieved a standard score of 80 or above on the full scale IQ of the Wechsler Intelligence Scales (WISC IV or WAIS IV: Wechsler, 2003, 2008, depending on the chronological age of the participants) were included in the sample. A summary of the participants' characteristics is shown in Table 4.1.

All children were recruited via local community contacts in northeast Italy, in either specialized centers for neurodevelopmental disorders, or local schools for TD.

The ASD children received an independent clinical diagnosis of either High Functioning Autism (n = 30) or Asperger syndrome (n = 16), according to DSM-IV-TR (APA, 2000) or ICD-10 (World Health Organization, WHO, 1992) criteria. In addition, they scored above the threshold on the Autism Diagnostic Interview-Revised (ADI-R; Rutter et al., 2005), performed within the normal range (≥ 7) on the Vocabulary subtest (WISC IV or WAIS IV: Wechsler, 2003, 2008, depending on the chronological age of the participants) and were free of medication (see Table 4.1).

Children in the NLD group were diagnosed by either private practitioners (child psychiatrists or psychologists) or through the Child Neuropsychiatry Department at the Hospital to which they referred. The diagnosis was confirmed through review of previous testing if recent, or through an updated assessment consistently with the most recent recommended criteria (Mammarella & Cornoldi, 2014). Our confirmation of a diagnosis for NLD required (1) scores 1 standard deviation (or more) below the average in a visuospatial task (Rey-Osterrieth complex figure test [ROCFT]; Rey, 1968), (2) discrepancy between verbal and visuospatial intelligence (with scores higher than at least one standard deviation (≥ 15) in the verbal comprehension index, or in the vocabulary subtest, compared to the perceptual reasoning index), measured with WISC IV or WAIS IV (Wechsler, 2003, 2008) depending on the chronological age of the participants [*M* = 30.20, *SD* = 10.52, *Min-Max* = 15 – 46] (3) social skills impairment as assessed using an anamnestic interview. The interview was conducted with both parents in order to collect information on developmental history, family history and psychosocial functioning. Social skills impairments were also based on scores below the average on at least two subscales of pragmatics of language (parent form of the Children Communication Checklist – second edition; CCC-2; Bishop, 2013), (4) Average scores in a word reading task (DDE-2; Sartori, Job, & Tressoldi, 2007) and scores 1 standard deviation (or more) below the average in arithmetic fact retrieval tasks (depending on the age of the participants we used: AC-MT 6-11, Cornoldi, Lucangeli, & Bellina, 2012; AC-MT 11-14, Cornoldi & Cazzola, 2004; MT 3 advanced, Cornoldi, Pra Baldi, & Giofrè, 2017).

Children with ADHD were diagnosed by either private practitioners (child psychiatrists or psychologists) or through the Child Neuropsychiatry Department at the Hospital to which they referred. Our confirmation of a diagnosis for ADHD required T-scores of 65 or higher on the Conners' Parent Rating Scale (CPRS-R) (Conners, 2007), in the inattention and/or hyperactivity scale as well as meeting the criteria for DSM-IV-TR or DSM 5 (APA, 2000, 2013) diagnosis of ADHD using an anamnestic interview conducted with both the parents in order to collect information on these areas: medical and developmental history, family history and academic and psychosocial functioning.

The TD controls were healthy children with normal intelligence and no history of psychiatric, neurological and neurodevelopmental disorders, tested individually at school.

All participants were native Italian speakers, without visual or hearing impairments, or other neurological diagnosed conditions. Considering the NLD, ADHD and TD groups no child met the criteria for autism using the ADI–R (Rutter et al., 2005). Individuals with ASD, NLD or ADHD who had comorbid psychopathologies were excluded. The research ethics committee at the University of Padova, Italy, approved the study; all participants provided assent to participate in our research, and their parents signed an informed consent.

Analyses of Group Selection Measures

Preliminary analyses were conducted to determine whether the expected group differences were present. These results provided in Table 4.1 confirmed the significant effect of group for the visuospatial measures: Perceptual Reasoning Index (PRI) [F (3, 189) = 12.27, $p < .001$; $\eta^2_p = .16$] and ROCFT [F (3, 189) = 9.12, $p < .001$; $\eta^2_p = .13$], showing that participants with NLD had lower scores than the other groups. A significant main effect of group emerged also for the Vocabulary subtest (Wechsler, 2003, 2008) [F (3, 189) = 19.61, $p < .001$; $\eta^2_p = .24$], where the ASD group scored significantly lower than other groups, with no differences between these latter. Moreover, the ASD participants exhibited higher scores than other groups in all the scales of ADI-R (Rutter et al., 2005), confirming the presence of the autistic symptomatology: Reciprocal Social Interaction [F (3, 189) = 171.99, $p < .001$; $\eta^2_p = .73$], Language/Communication [F (3, 189) = 162.67, $p < .001$; $\eta^2_p = .72$], Repetitive Behaviors/Interests [F (3, 189) = 107.33, $p < .001$; $\eta^2_p = .63$].

Table 4.1 Characteristics of Groups: ASD, NLD, ADHD and TD.

Measures	ASD (n = 46) Mean (SD)	NLD (n = 21) Mean (SD)	ADHD (n = 31) Mean (SD)	TD (n = 95) Mean (SD)	Group Significance
Gender (M:F)	36:10	15:6	29:2	77:18	N.S.
Age (months)	161.99 (45.01)	144.24 (36.51)	138.94 (29.49)	155.03 (43.21)	N.S.
IQ[a]	96.74 (12.95)	96.95 (14.62)	106.94 (15.33)	111.48 (10.56)	NLD, ASD<ADHD (p=.03, p=.003), TD (p_s<.001)
PRI[a]	109.63 (14.93)	89.48 (18.26)	107.06 (17.75)	111.76 (14.03)	NLD<ASD, ADHD, TD (p_s<.001)
Vocabulary[a]	9.33 (2.11)	12.76 (2.88)	11.71 (2.75)	12.66 (2.52)	ASD<NLD, ADHD, TD (p_s<.001)
ADI-R: A	19.30 (6.66)	5.71 (2.97)	4.45 (2.85)	3.25 (2.70)	ASD>NLD, ADHD, TD (p_s<.001)
ADI-R: B	13.96 (5.47)	3.71 (1.77)	3.19 (1.66)	2.20 (1.70)	ASD>NLD, ADHD, TD (p_s<.001)
ADI-R: C	6.63 (4.02)	.62 (.50)	.61 (.80)	.42 (.50)	ASD>NLD, ADHD, TD (p_s<.001)
ROCFT Copy	23.19 (7.31)	18.21 (6.64)	23.08 (5.84)	26.11 (6.21)	NLD<ASD (p=.03), ADHD (p=.05), TD (p<.001)

Note. [a] Standard scores on the Wechsler Intelligence Scale for Children—Fourth Edition (for participants aged 8 to 16 years) or Wechsler Adult Intelligence Scale – Fourth Edition (for participants from 16 years onwards). IQ = Intelligence Quotient; PRI = Perceptual Reasoning Index. ADI-R = Autism Diagnostic Interview-Revised (Rutter et al., 2005): A = Reciprocal Social Interaction, B = Language/Communication, C = Repetitive Behaviors/Interests; Elevated scores on the ADI-R reflect greater levels of autistic symptomatology. ROCFT = Rey-Osterrieth complex figure test (Rey, 1968).

Additional group selection measures for the NLD and ADHD groups were used, comparing them with TD. In particular for the ADHD symptoms the CPRS-R (Conners, 2007) was used and the significant effect of group emerged for all subscales: Oppositional [F (2, 79) = 4.50, p = .01; η^2_p = .11], Inattention [F (2, 79) = 41.67, p < .001; η^2_p = .52], Hyperactivity [F (2, 79) = 8.53, p < .001; η^2_p = .18], ADHD [F (2, 79) = 42.19, p < .001; η^2_p = .52]. Results showed, for all the subscales, higher scores for participants with ADHD than TD ($p_s \leq$.05) and for the scale Inattention and ADHD higher scores for the ADHD than NLD (p_s=.002). Moreover, for the NLD group higher scores than TD group emerged for the Oppositional, Inattention and ADHD subscales ($p_s \leq$.03). Also for the Pragmatics of Language, the ADHD and NLD groups ha lower scores than TD. In particular, the significant effect of group emerged for the following subscales of the CCC-2 (Bishop, 2013): Initiation [F (2, 79) = 8.43, p < .001; η^2_p = .18], Scripted Language [F (2, 79) = 7.85, p = .001; η^2_p = .17], Context [F (2, 79) = 10.21, p < .001; η^2_p = .21], Nonverbal communication [F (2, 79) = 8.40, p < .001; η^2_p = .18], Social relations [F (2, 79) = 23.34, p < .001; η^2_p = .37]. The ADHD group had worse performance than TD group in all these subscales ($p \leq .001$) and the NLD group had worse performance than TD group in the initiation, scripted language and social relations subscales ($p \leq .05$). On the contrary no significant difference emerged for the Interests subscale [F (2, 79) = 2.76, p = .07; η^2_p = .07]. Finally, words reading (DDE-2; Sartori, Job, & Tressoldi, 2007) and arithmetic fact retrieval tasks (AC-MT 6-11, Cornoldi et al., 2012; AC-MT 11-14, Cornoldi & Cazzola, 2004; MT advanced 3, Cornoldi et al., 2017) were administered. A significant main effect of group emerged for the reading task [F (2, 79) = 6.20, p = .003; η^2_p = .14], participants with ADHD showed worse performance than TD group (p=.003), while no differences emerged for the NLD group than TD. Also for the arithmetic facts task a significant main effect of group emerged [F (2, 79) = 6.99, p = .002; η^2_p = .15], both the ADHD and NLD groups showed performance less accurate than TD group (p=.002, p=.03 respectively).

4.4.2 Materials

The tasks used in the current study are the same as those used in study 1; for clarity, their description is also included in this section.

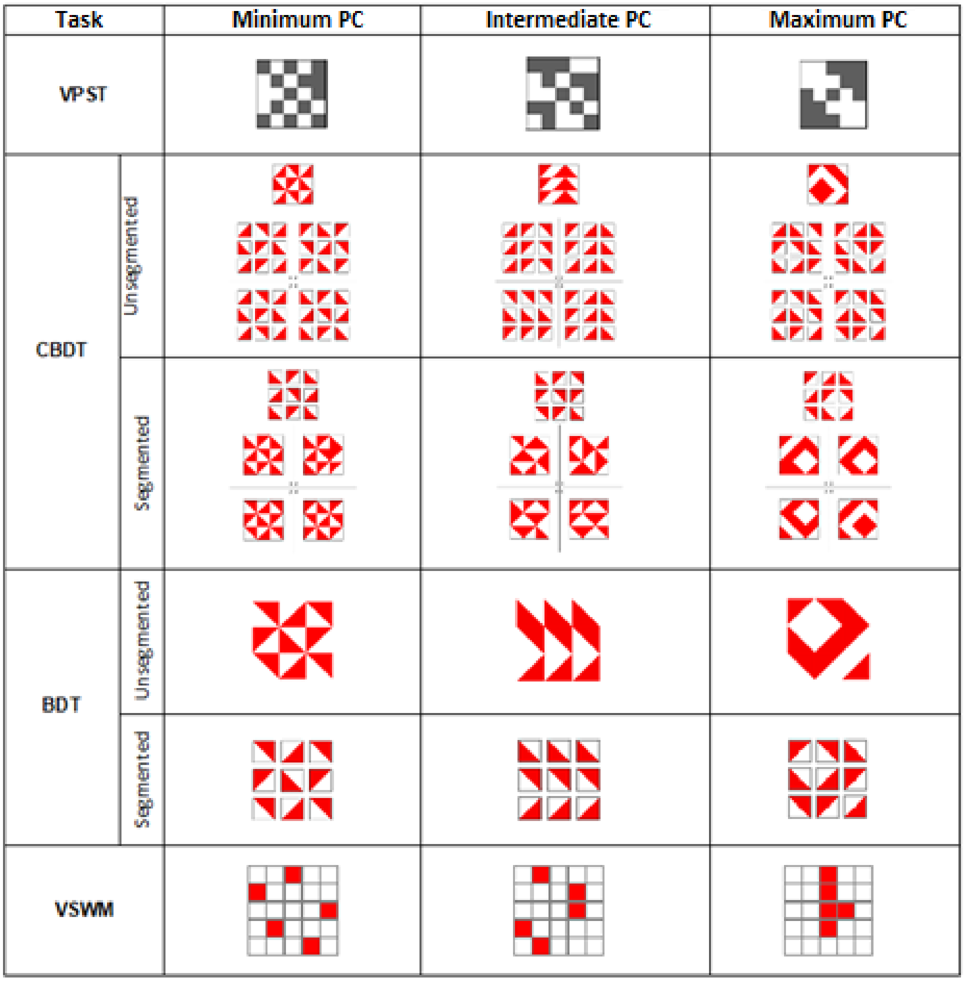
For the all tasks, the stimuli were prepared with different levels of PC, which is a global property of the figures that can be manipulated by varying the number of “adjacencies” of opposite-colored edges between the blocks/cells (Caron et al., 2006). A given figure could have a minimum level of PC (many edge cues and adjacencies of opposite-colored blocks/cells, forming local configurations), an intermediate level of PC (half the blocks/cells comprising the figure had adjacencies with opposite-colored blocks/cells, and the other half had adjacencies with same-color blocks/cells), or a maximum level of PC (the blocks/cells had adjacencies with others of the same color, forming global configurations) (see Figure 4.1).

As can be seen from the Figure 4.1 when the level of PC is minimum, the elements comprising a figure are more amenable to being processed locally, focusing on the different squares; when the level of PC is maximum, the arrangement of the squares forming the figure tends to prompt their global processing.

Visuospatial processing speed task (VPST)

The VPST assessed perceptual encoding speed for meaningless visual patterns. The stimuli consisted of 5 x 5 grids, each containing 25 square cells white and grey distributed according to different levels of PC. Participants had to look at the target figure on the right and then choose the corresponding figure presented among four distractors as quickly as possible. The task consisted of 36 items presented in three different conditions: minimum, intermediate and maximum level of PC (12 for each level) and participants had 1 minute to complete each condition (See Figure 4.1). For accuracy scoring, one point was awarded for each correct answer and zero for answers that were wrong or given beyond the time limit.

Figure 4.1 Examples of stimuli drawn from the VPST, CBDT (unsegmented and segmented conditions), BDT (unsegmented and segmented conditions) and the VSWMT, presented for three levels of PC (minimum, intermediate and maximum).



Note: VPST: Visuospatial processing speed task; *CBDT:* Computerized block design task; *BDT:* Block Design Task; *VSWMT:* Visuospatial Working Memory Task; *PC:* Perceptual Cohesiveness.

Computerized block design task (CBDT)

The CBDT was a modified version of a matching task derived from the study by Caron et al. (2006; see also Cardillo, et al. 2017). Our modified version comprised two conditions. The unsegmented condition consisted of matching an unsegmented target figure with a corresponding segmented figure presented among three segmented distractors. The segmented condition consisted of matching a segmented target figure to a corresponding unsegmented figure presented among three unsegmented distractors. The distractors differed from the target by color inversion, local differences and target rotation. Both versions consisted of 36 trials (12 for each level of PC: minimum, intermediate and maximum). Participants were told that they would see a figure at the top of the screen (target stimulus) and they were asked to choose the figure corresponding to the target stimulus as quickly as possible from among four options presented at the bottom (See Figure 4.1). Answers were given by indicating the number corresponding to the correct response (and a score of 1 was assigned to each correct figure match). The experimenter pressed the spacebar to record response times (RTs) and then recorded the answer by pressing one of four keys on a keyboard. The accuracy of the answers and the RTs (in milliseconds) were analyzed. One point was awarded for each correct answer and zero for a wrong answer.

Modified Block Design Task (BDT)

The Modified BDT (Caron et al., 2006) assessed visuo-constructive abilities and visuospatial processing styles. Participants were shown a two-dimensional red and white geometrical design and then asked to reproduce it by assembling a set of blocks comprising six colored surfaces (two red, two white, two half-red and half-white). The material for this task consisted of 18 items presented in two different conditions: unsegmented and segmented. The items differed in terms of level of PC (minimum, intermediate and maximum), and were balanced for matrix size (4, 9, or 16 blocks). Figure 4.1 shows examples of the stimuli. For each matrix size, a control condition measuring the motor speed component involved in BDT construction was added, in the form of a monochromic square presented in the segmented and the unsegmented condition. The task was administered according to the Wechsler's instructions (WISC, Wechsler, 2003). Participants were asked to respond as quickly and accurately as possible. A time limit was set for each block configuration, which was 75, 120 and 180 s, for the 4-, 9-, and 16-block designs, respectively (see Cardillo, et al. 2017). Performance was timed from the moment the stimulus was placed in front of the participant up until the design was completed or the time limit elapsed. Following the procedure, proposed by Caron et al. (2006), the order of presentation of the trials was identical for all participants and the unsegmented condition was presented before the segmented condition to avoid a facilitation effect. The number of blocks correctly placed on each design was considered to measure accuracy, and RTs (in seconds) were also recorded[4].

Visuospatial working memory task (VSWMT)

The VSWMT is a computerized task for assessing visuospatial working memory (Cardillo et al., under revision). The task consisted of 36 items in the form of white matrixes containing increasing numbers of cells, some of which were red (span: from 4 to 9). Stimuli were balanced for level of PC (minimum, intermediate and maximum), and each level of PC included two items per span (from 4 to 9). The stimuli with a high level of PC were easy to group into a global configuration and consequently prompted a global processing, whereas the figures with low level of PC were more amenable to being processed locally, by focusing on the different components (Figure 4.1). Participants were shown a matrix for 3 s, and asked to memorize the configuration. Then, after a .5 s inter-stimulus interval, they were asked to recall the pattern on a completely blank matrix of the same size by using the mouse to mark the

[4] In order to control the response times for individual differences in motor speed without a cognitive load, the time taken to carry out the control condition had been subtracted from the response times of each item. In this way the response times were analysed by controlling for the motor speed of each participant.

red cells previously seen. The order of presentation proceeded from the lower to the higher spans, while a random order was used to present the items within each span. The partial credit score was used for scoring purposes (Conway, et al. 2005; Giofrè & Mammarella, 2014), i.e., the proportions of cells correctly recalled on each matrix.

4.4.3 Procedure

Participants were tested in a quiet room during two individual sessions lasting approximately 40 minutes each. Tasks were administered in a counterbalanced order. Instructions were given for each task, and participants practiced with each task before starting the experiment. The CBDT and the VSWMT were administered using a laptop computer with a 15-inch LCD screen, and the experimental procedure was programmed with the E-Prime 2.0 software (Schneider, & Zuccolotto, 2007).

4.5 Results

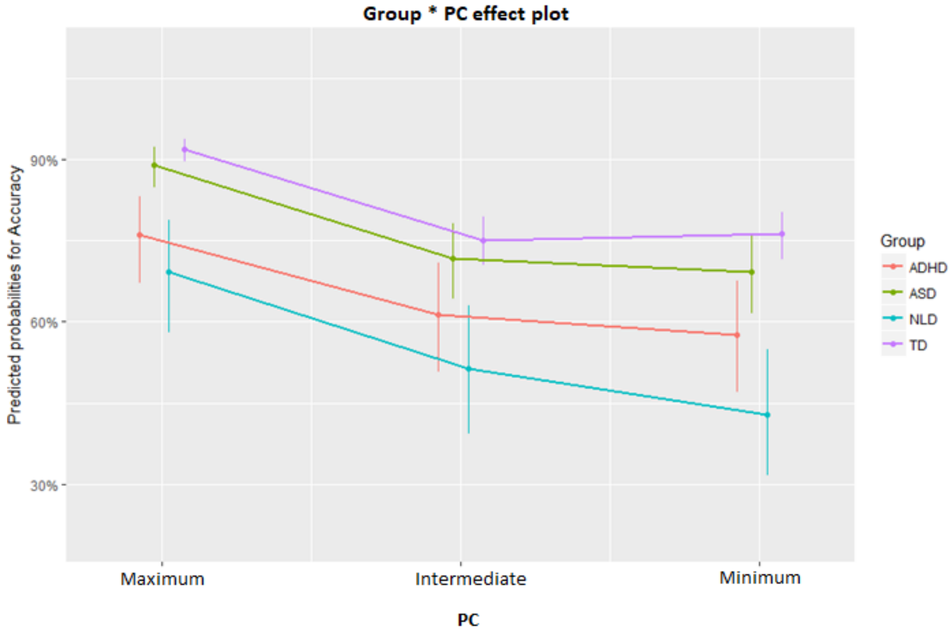
Data Analyses: Data analyses were conducted using R (R Core Team, 2015), modeled using a mixed-effects model approach and run using the "lme4" package (Bates et al., 2015). The significance of both fixed and random effects was tested through a series of likelihood ratio tests for nested models based on the chi-square distribution (Pinheiro & Bates, 2000). The Akaike Information Criterion (AIC; Akaike, 1974) was also reported for each model; lower AIC indicates a better model.

The accuracy data obtained were analyzed using a generalized linear mixed-effects model approach (Baayen, 2008; Jaeger, 2008) with the family as "binomial" or "poisson" depending on the scores distribution. In addition, *RT*s for correct answers were analyzed for the CBDT and BDT adopting a generalized linear mixed approach with the function family as “Gamma” and link as “log”.

The following fixed effects and their interactions, were tested for all tasks: Group (4 levels: ASD, NLD, ADHD, TD) and level of PC (3 levels: Minimum, Intermediate, Maximum). In addition, the fixed effect of Condition (2 levels: Segmented, Unsegmented) for the CBDT and BDT was also considered. Participants were included as random effects to consider their variability in each mixed-effect model. Graphical effects were obtained using the “sjplot” package (Lüdecke & Schwemmer, 2017).

VPST- Accuracy. Concerning the fixed effect of Group, a significant main effect was found [$\chi 2(3) = 34.66$, $p < .001$ (full model: $AIC = 7229.4$; model without Group: AIC = 7258.1)]. The model coefficients showed that the NLD and ADHD groups were less accurate than ASD and TD groups (p_s <.001). No other differences emerged between the groups. The main effect of the level of PC was significant too [$\chi 2(2) = 289.15$, $p < .001$ (model without level of PC: AIC = 7514.6)]. The model coefficients showed that the performance was more accurate with stimuli characterized by a maximum level of PC than for intermediate or minimum levels (*p*s<.001), no other differences emerged. The interaction between Group and Level of PC (see Figure 4.2) was significant [$\chi 2(6) = 13.289$, $p = .04$ (model with Interaction: AIC = 7228.1)]. The NLD group showed lower accuracy than TD and ASD groups in all the three levels of PC (*p*s≤.002). The ADHD group was less accurate than TD group in all the PC levels (*p*s≤.006), moreover it was less accurate than ASD only in the maximum level of PC ($p = .005$). No other differences emerged between groups.

Figure 4.2 Predicted probabilities for accuracy by Group and PC level in the VPST. Error bars represent 95% confidence intervals.



CBDT- Accuracy. Concerning the fixed effect of Group, a significant main effect was found [χ2(3) = 17.84, p < .001 (full model: *AIC* = 10899; model without Group: AIC = 10911)]. The model coefficients showed that the NLD group was less accurate than all the other groups (p_s <.02). No other differences emerged between groups. Also the main effect of condition was significant [χ2(1) = 4.97, p = .03 (model without Condition: AIC = 10902)]. The model coefficients showed that participants had a better performance in the unsegmented condition than in the segmented (p = .02). The main effect of the level of PC was significant too [χ2(2) = 46.53, p < .001 (model without level of PC: AIC = 10941)]. The model coefficients showed that the performance was more accurate with stimuli characterized by a maximum level of PC than intermediate or minimum levels (ps<.001), no other differences emerged.

The interactions between Group and Condition [χ2(3) = 4.14, p = .24 (model with Interaction: AIC = 10901)] and Group and Level of PC [χ2(6) = 5.21, p = .52 (model with Interaction: AIC = 10878)] were not significant. While the interaction between Level of PC and Condition was significant [$\chi 2(2) = 24.05$, $p < .001$ (model with Interaction: AIC = 10879)]. In the segmented condition, participants were less accurate with stimuli with medium level of PC than with maximum ($p < .001$) or minimum levels ($p = .002$). In the unsegmented condition participants were less accurate with stimuli with medium and minimum levels of PC than with maximum levels (*p*s<.001), no other differences emerged.

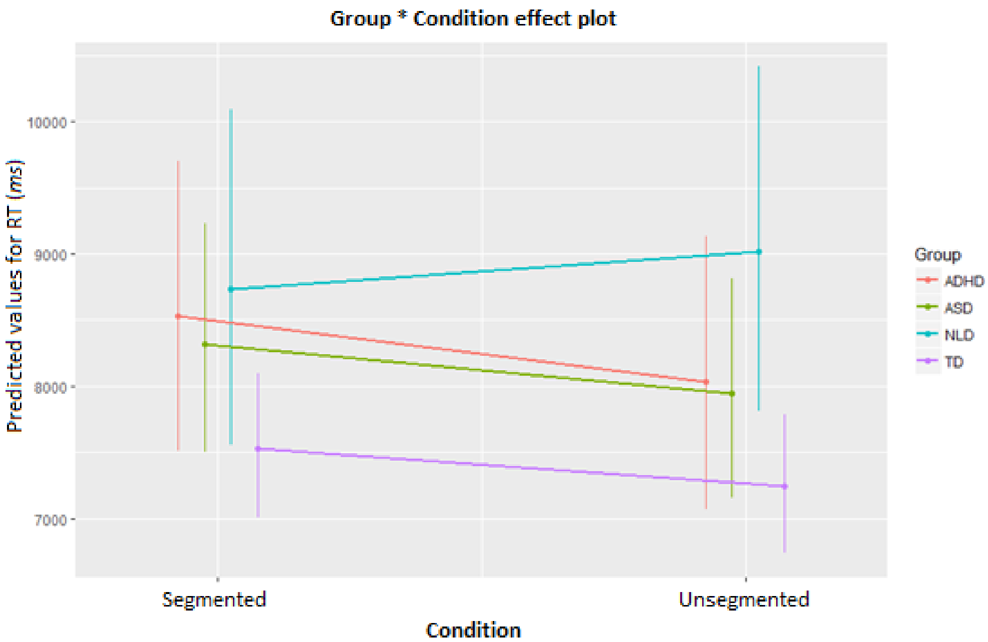
Finally the interaction between Group, Condition and Level of PC was not significant [$\chi 2(6) = 6.97$, $p = .32$ (model without interaction: AIC = 10887; model with Interaction: AIC = 10892)].

CBDT- Response times (RTs). No main effect of Group emerged [$\chi 2(3) = 6.84$, $p = .08$ (full model: *AIC* = 225373; model without Group: AIC = 225374)], but the main effect of Condition was significant [$\chi 2(1) = 18.19$, $p < .001$ (model without Condition: *AIC* = 225390)]. The model coefficients showed that participants completed the unsegmented condition faster than the segmented one ($p <.001$). The main effect of the level of PC was significant too [$\chi 2(2) = 1779.6$, $p < .001$ (model without PC: *AIC* = 227149)]. The model coefficients showed that participants completed the task faster when stimuli had maximum level of PC than intermediate or minimum levels ($p_s < .001$), and they were faster in the intermediate than in the minimum level ($p < .001$). The analysis also revealed the significant interaction between Group and Condition [$\chi 2(3) = 7.94$, $p = .05$ (model with Interaction: *AIC* = 225372)] (see Figure 4.3).

The model coefficients showed that in the unsegmented condition the NLD group was slower than the TD group ($p = .02$); no other differences emerged between groups for both conditions unsegmented and segmented. The interaction between

Group and level of PC was significant [$\chi 2(6) = 13.34$, $p = .04$ (model with Interaction: *AIC* = 225372)]. The NLD group showed slower performance than TD group in the maximum (p = .02) and intermediate (p = .04) level of PC, while no differences emerged for the minimum level. No differences between other groups emerged. In addition, the interaction between level of PC and Condition was significant [$\chi 2(2)$ = 30.21, $p < .001$ (model with Interaction: *AIC* = 225347)]. Only in the maximum (p =.03) and intermediate ($p < .001$) level of PC participants were faster in the unsegmented condition than the segmented one, while no differences emerged between conditions for the minimum levels of PC. Finally, the interaction between Group, Condition and level of PC was no significant [$\chi 2(6) = 1.89$, $p = .93$ (model without interaction: AIC = 225344; model with Interaction: *AIC* = 225354)].

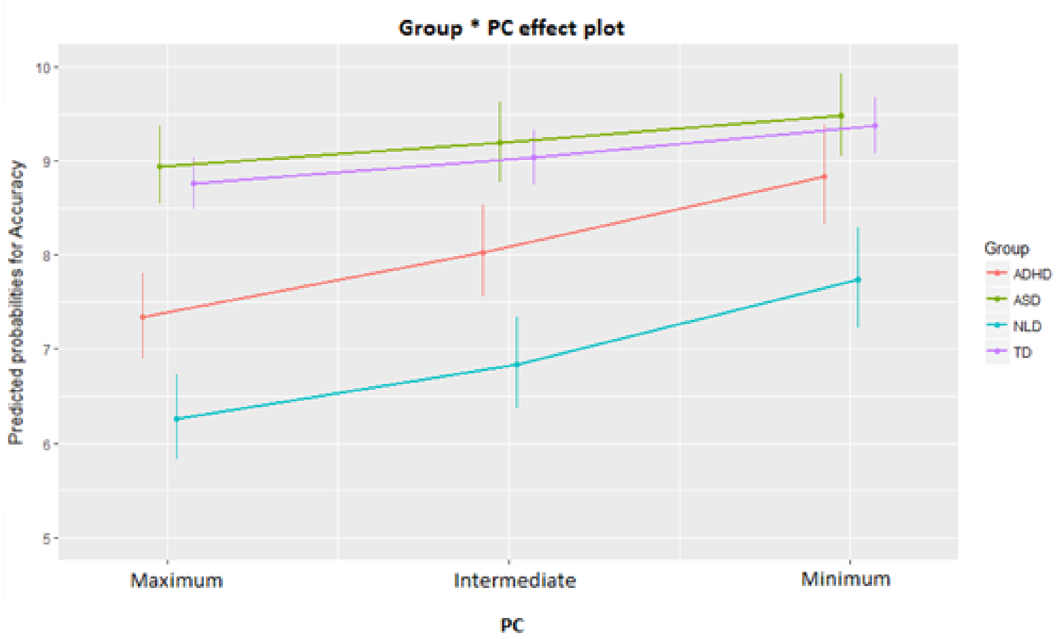
Figure 4.3 Predicted values for Response Times (*ms*) by Group and Condition in the CBDT. Error bars represent 95% confidence intervals.



BDT – Accuracy. A significant main effect of group was found [$\chi 2(3) = 65.35$, $p < .001$ (full model: *AIC* = 46877; model without Group: AIC = 46936)]. The model coefficients showed that both NLD and ADHD were less accurate than ASD and TD groups (p_s<.001) and NLD group was less accurate than ADHD group (p<.001). No differences emerged between ASD and TD groups. The main effect of Condition was significant [$\chi 2(1) = 331.42$, $p < .001$ (model without Condition: *AIC* = 47206)]. The model coefficients showed that participants were less accurate in the unsegmented condition than the segmented one (p <.001). Also the main effect of the level of PC was significant [$\chi 2(2) = 91.33$, $p < .001$ (model without PC: *AIC* = 46964)]. The model coefficients showed that participants were more accurate on the minimum level of PC than on the intermediate or maximum levels (p_s<.001), and they were more accurate on the intermediate than in the maximum level ($p < .001$). In addition, the analysis revealed a significant interaction between Group and Condition, [$\chi 2(3) = 206.19$, $p < .001$ (model with Interaction: *AIC* = 46752)]. The model coefficients showed that in the unsegmented condition both NLD and ADHD groups were less accurate than ASD and TD groups (p_s<.001) and NLD group was less accurate than ADHD group (p<.001). Instead, in the segmented condition only the NLD group was less accurate than ASD and TD groups (p_s<.001) with no other significant differences. The interaction between Condition and level of PC was significant too [$\chi 2(2) = 114.42$, $p < .001$ (model with Interaction: *AIC* = 46766)]. The model coefficients showed that in the unsegmented condition participants were more accurate in the minimum level of PC than in the intermediate or maximum levels (p_s<.001), and they were more accurate in the intermediate than in the maximum level ($p < .001$). Conversely, in the segmented condition no differences between levels of PC emerged. Similarly, as shown in Figure 4.4, the interaction between Group and level of PC was significant [$\chi 2(6) = 32.24$, $p < .001$ (model with Interaction: *AIC* = 46856)]. The model coefficients showed that NLD group was less accurate than all the other groups in all the PC levels (p_s<.004), the

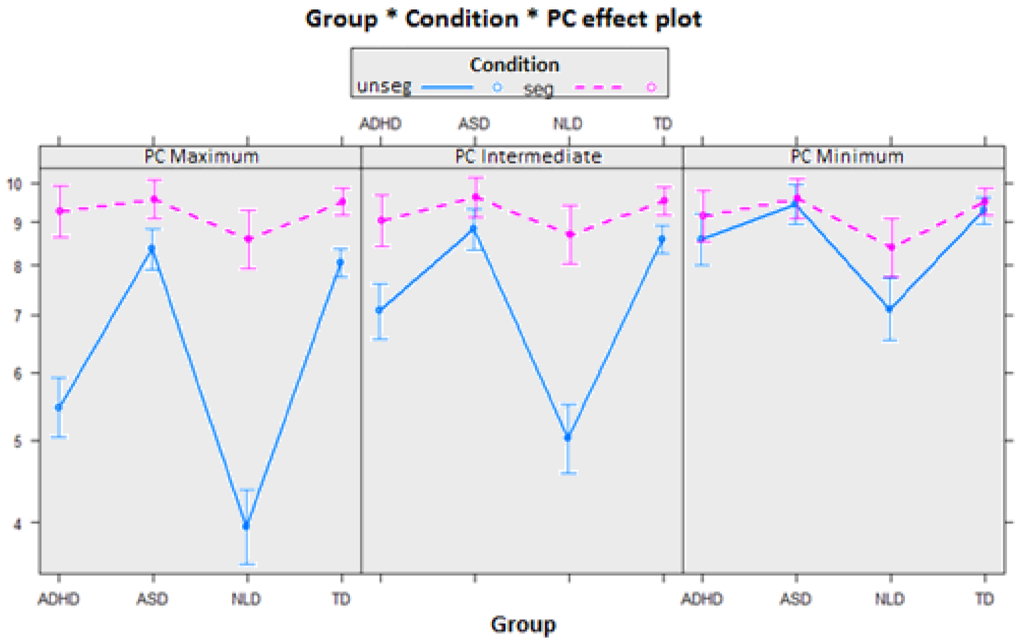
ADHD group was less accurate than ASD and TD groups only in the maximum and intermediate PC levels (p_s<.001) while no differences emerged for the minimum level. Finally no differences emerged between ASD and TD groups in any PC level.

Figure 4.4 Predicted probabilities for accuracy by Group and PC level in the BDT. Error bars represent 95% confidence intervals.



The interaction between Group, Condition and level of PC was significant too [$\chi 2(6) = 71.75$, $p < .001$ (model without interaction: AIC = 46539; model with Interaction: *AIC* = 46479)] (see Figure 4.5). In the unsegmented condition the NLD group was less accurate than the all other groups in the minimum and intermediate PC levels (p_s<.001), in the maximum PC level this group was less accurate than only ASD and TD groups (p_s<.001). Differently, the ADHD group showed performance less accurate than ASD and TD groups only in the intermediate and maximum PC levels (p_s<.001), with no differences in the minimum level. Finally, in the segmented condition participants with NLD showed performance less accurate than ASD and TD groups only in all the PC levels ($p_s \leq .01$). No other differences emerged between groups.

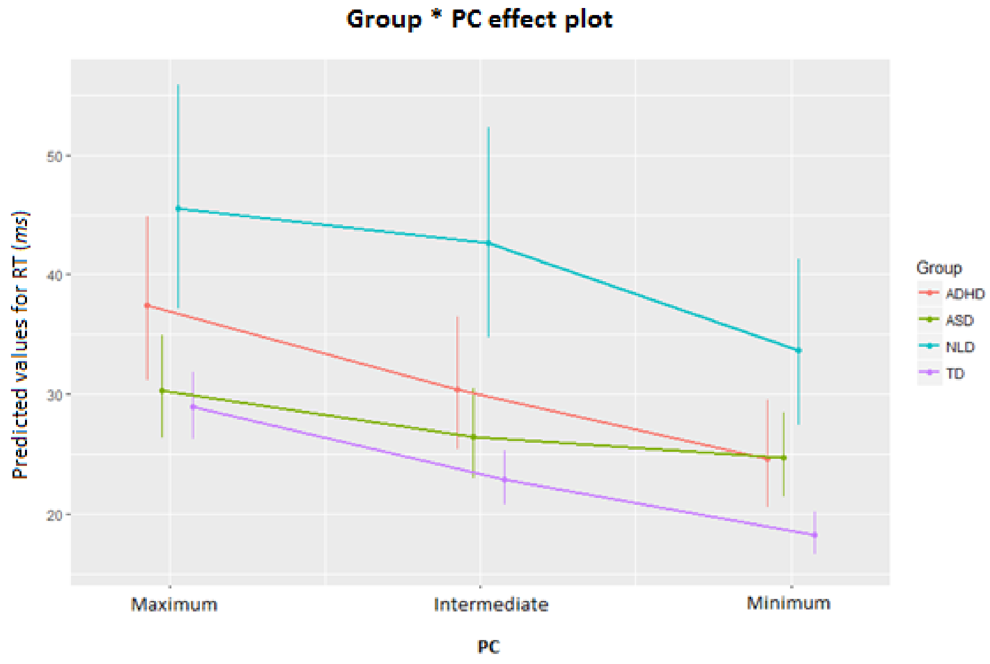
Figure 4.5 Predicted probabilities for accuracy by Group, Condition and PC level in the BDT. Error bars represent 95% confidence intervals.



BDT - Response times (RT). A significant main effect of group was found [$\chi2(3) = 30.15$, $p < .001$ (full model: *AIC* = 59799; model without Group: AIC = 59823)]. The model coefficients showed that the NLD group had slower performance than all other groups ($p_s \leq .02$) and the ASD and ADHD was slower than TD group ($p = .04$ and $p = .003$ respectively). No differences emerged between ASD and ADHD groups.

The main effect of Condition was significant [$\chi2(1) = 1570.2$, $p < .001$ (model without Condition: *AIC* = 61367)]. The model coefficients showed that participants completed the unsegmented condition more slowly than the segmented one ($p < .001$). Also the main effect of the level of PC was significant [$\chi2(2) = 205.6$, $p < .001$ (model without PC: *AIC* = 60001)]. The model coefficients showed that participants completed the task faster on the minimum level of PC than on the intermediate or maximum levels (p_s<.001), and they were faster on the intermediate than in the maximum level (p<.001). In addition, a significant interaction between Group and Condition was found, [$\chi 2(3) = 57.63, p < .001$ (model with Interaction: $AIC = 59748$)]. The model coefficients showed that in the unsegmented condition both the ADHD and NLD groups had slower performance than TD and ASD groups ($p_s \leq .006$), with no other significant differences. Differently in the segmented condition, the NLD group showed slower performance than ASD and TD groups (p_s<.001). No other differences emerged between the other groups. The interaction between Condition and level of PC was significant too [$\chi 2(2) = 176.21, p < .001$ (model with Interaction: $AIC = 59627$)]. The model coefficients showed that in the unsegmented condition participants had faster performance on the minimum level of PC than on the intermediate or maximum levels (p_s<.001), and on the intermediate than in the maximum level ($p < .001$). Conversely, in the segmented condition no differences between levels of PC emerged. In addition, as shown in Figure 4.6, the interaction between Group and level of PC was significant too [$\chi 2(6) = 19.34, p = .004$ (model with Interaction: $AIC = 59792$)]. The model coefficients showed that participants with NLD had slower performance than the all other groups in both minimum and intermediate PC levels ($p_s \leq .04$), and in the maximum PC level they were slower than ASD and TD groups ($p_s \leq .002$). In addition, the ADHD group was slower than the TD group in all the PC levels ($p_s \leq .01$) and the ASD group was slower than TD in the minimum and intermediate levels ($p_s \leq .003$). Finally, the interaction between Group, Condition and level of PC was not significant [$\chi 2(6) = 5.25, p = .51$ (model without Interaction: $AIC = 59578$; model with Interaction: $AIC = 59585$)].

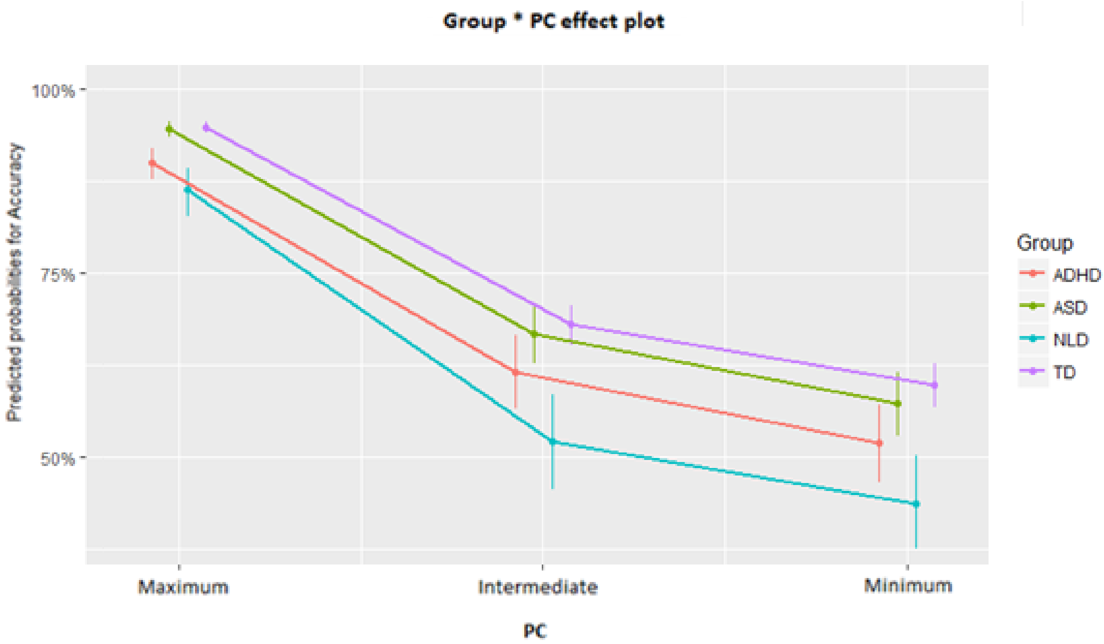
Figure 4.6 Predicted values for Response Times (*sec.*) by Group and PC level in the BDT. Error bars represent 95% confidence intervals.



VSWMT – Accuracy. A significant main effect of group was found [$\chi 2(3)$ = 29.76, p < .001 (full model: AIC = 21241; model without Group: *AIC* = 21265)]. The model coefficients showed that the NLD group had lower performance than all other groups ($p_s \leq$.03) and the ADHD group was less accurate than ASD and TD groups (p_s $\leq$.03). No differences emerged between the ASD and TD groups. In addition, there was a main effect of PC [$\chi 2(2)$ = 6506.8, p < .001 (model without PC: *AIC* = 27744)]. The model coefficients showed that participants better recalled stimuli characterized by a maximum level of PC than intermediate or minimum levels (p_s<.001), and an intermediate level of PC elicited better performance than minimum level (p<.001). As shown in Figure 4.7, the analysis also revealed a significant interaction between Group and level of PC [$\chi 2(6)$ = 39.229, p < .001 (model with Interaction: *AIC* = 21214)]. The model coefficients showed that both the ADHD and NLD groups showed worse performance in the maximum level of PC than the ASD and TD groups (p_s<.001), with no differences between each other. In the intermediate and minimum levels of PC, the

ADHD group showed performance more accurate than NLD group (p = .01 and p = .05 respectively) and less accurate than TD group (p = .02 and p = .008 respectively). In addition, the NLD group registered worse performance also in the intermediate and minimum PC levels than ASD and TD groups (p_s<.001). No other significant differences emerged.

Figure 4.7 Predicted probabilities for Accuracy by group and PC in the VSWMT. Error bars represent 95% confidence intervals.



4.6 Discussion

Despite visuospatial abilities have a fundamental role in the cognitive profile of NLD (Cornoldi et al., 2016) and have shown peculiarities in the neuropsychological profiles of disorders such as ASD without ID (Caron et al., 2006; Semrud-Clickeman et al., 2010) and ADHD (Martinussen et al. 2005), only few studies specifically investigated their importance within a clinical perspective. In particular, considering that these disorders are characterized by overlaps of some symptoms, which create a challenge for their diagnosis (Williams et al., 2008), it is surprising that only few studies have compared the neuropsychological functioning of children across these disorders (e.g. Ryburn et al., 2009; Semrud-Clickeman et al., 2010, 2014). In addition, on our knowledge no studies have previously investigated a so wide range of visuospatial abilities comparing individuals with ASD without ID, NLD and ADHD.

Starting from this premise, the main aim of the present study was to investigate the visuospatial abilities in the cognitive profile of individuals with ASD without ID, NLD and ADHD compared with a TD group. Furthermore, giving that some studies involving samples with ASD illustrated the importance of cross-syndrome comparisons about global vs local visuospatial processing (e.g. D'Souza et al., 2016), our study investigated the interplay between visuospatial abilities and local and global processing in these three clinical groups. For this reason, tasks assessing visuospatial processing speed, visuo-perceptual and visuo-constructive abilities and VSWM based on the modified BDT paradigm (Caron et al., 2006; Wechsler, 2003, 2008) were used. For all tasks, the influence of the global-local processing on participants' performance was analyzed through the manipulation of the PC of the stimuli.

Our results in the VPST assessing visuospatial processing speed revealed that both NLD and ADHD groups were less accurate than the ASD and TD groups, showing impaired visuospatial processing speed skills. This is in line with previous studies, which found in a subtype of children with NLD a processing speed disorder (Grodzinsky, Forbes, & Bernstein, 2010) and slower processing speed in children with ADHD (Weigard & Huang-Pollock, 2017). Mixed findings, instead were reported in literature for ASD: lower (Mayes, & Calhoun, 2007; Oliveras-Rentas et al., 2012), higher (Scheuffgen et al., 2000) or comparable (Wallace et al., 2009) processing speed abilities were observed in individuals with ASD compared to controls. Our results, consistently with Wallace and colleagues (2009) did not show differences between ASD and TD controls in the VPST. Concerning the global-local processing, in this task, all groups showed better performances with stimuli presenting global than local configurations. This result, consistently with the global precedence hypothesis (Navon, 1977), proved that it is easier for participants to recognize and discriminate quickly configurations when a global processing of the stimuli is demanded, whereas the need for a local processing makes more difficult to quickly complete the task. Both NLD and ADHD performed worse than TD controls in all the level of PC showing that their impairments in this task were not related to the global or local presentation of the stimuli.

Concerning visuo-perceptual abilities, assessed with the CBDT, only the NLD group showed less accurate performance than all the other groups. This result argues in favor of difficulties in the visuo-perceptual processing for participants with NLD and is in line with previous studies, in which difficulties in discriminating or recognizing visual configuration were observed (Chow & Skuy, 1999; Mammarella & Pazzaglia, 2010; Roman, 1998; Semrud-Clikeman et al., 2010). On the other hand, as for the global-local processing, even in this task, the effect of the condition and coherence of the stimuli emerged, in line with the global precedence hypothesis (Navon, 1977). In fact, all groups showed faster and more accurate performances with unsegmented stimuli than segmented ones and when global (maximum level of PC) than local (minimum level of PC) configurations were presented. Finally, the NLD group had slower performance than TD group only in the unsegmented condition showing difficulties in integrating local configurations (the segmented response options) in a coherent whole.

Results concerning visuo-constructive abilities, assessed by the modified BDT, showed that participants with NLD completed the task slower and with less accuracy than all the other groups for the unsegmented condition (i.e., global presentation). Moreover, NLD children had worse performance (lower accuracy and slower response times) than TD group also in the segmented condition. The impairment in visuo-constructive abilities emerged across all the PC levels, and highlighted a marked deficit for the NLD group affecting their performance at both local and global levels. This outcome is consistent with previous studies which showed how children with NLD failed in tasks requiring part-to-whole reconstructions (e.g., Cornoldi et al., 2016; Drummond et al., 2005). Children with ADHD showed performance less accurate and slower than ASD and TD groups only in the unsegmented condition, while no differences emerged for the segmented one. In particular, they performed worse than ASD and TD children with figures characterized by high coherence (maximum and intermediate level of PC), while no differences in accuracy between ADHD, ASD and TD groups emerged with local stimuli (minimum level of PC). These results suggest that our children with ADHD had no difficulties when the task proposed configurations that favored a local analysis of the stimuli. *Vice-versa*, ADHD children seem to invest more effort than ASD and TD children when asked to reconstruct global configurations: condition in which it becomes necessary to analyze the picture and identify the relationships between its components in order to correctly complete the task. Finally, children with ASD were slower than TD only in the minimum and intermediate levels of PC, while in the maximum level no differences emerged. This result is consistent with previous studies and suggested that the group with ASD showed a diminished sensitivity to perceptual coherence (Caron et al., 2006; Shah & Frith, 1993).

As for the VSWMT, children with NLD obtained lower performances than the all other groups for the medium and intermediate levels of PC, and they were less accurate than ASD and TD groups in the maximum level of PC. Children with ADHD showed lower performances than TD in all the PC levels and were less accurate than ASD in the maximum level of PC. Thus we can conclude that both NLD and ADHD showed, consistently with previous studies (see Mammarella & Cornoldi, 2014; Martinussen et al. 2005), visuospatial working memory deficits, with the first group more impaired than the second one. Finally, as for the global-local processing, even in this task the effect of the perceptual coherence emerged, showing for all groups better performances with global (maximum level of PC) than local (minimum level of PC) configurations.

To sum up, the NLD group was characterized by marked deficits in all the visuospatial domains examined when compared to the other groups, confirming that impairments in the visuospatial skills are core and distinctive symptoms of this disorder. It is also interesting to note that, similar to findings in the sample of Semrud-Clikeman, Fine & Bledsoe (2014), a high amount of variability on the experimental measures within the NLD sample compared to the others is observed. Differently, children with ADHD showed a heterogeneous visuospatial profile with impairment in the visuospatial processing speed domain, some difficulties in visuo-constructive abilities and VSWM but typical visuo-perceptual abilities. Finally, children with ASD performed normally in all the examined domains, with the sole exception of the visuo-constructive task in which this group showed slower response times and a diminished sensitivity to perceptual coherence.

Concerning the group with ASD it is worth to note that in this study, unlike in Study 1, it was not divided by IRP. For this reason, the results of Study 1 are only partially confirmed in this study and the substantial differences emerged with the typical development group in the Study 1 did not emerge in this study.

Further studies are needed to confirm and extend the present results and to overcome the limitations of the present study. Future research should compare the performance of children with NLD with a group with ASD without ID selected for low PRI scores, in order to understand whether this subgroup of ASD – although not representative of the ASD without ID population – share more characteristics with the NLD group. In addition, it would be interesting to compare individuals with NLD, ADHD and ASD also in other domains of cognition such us pragmatics of language and social perception skills, to highlight any cross-disorder similarities or differences and decrease possible overlaps in diagnosis.

Concluding, in our view the present study is one of the first successful attempts to shed light on the visuospatial functioning of three neurodevelopmental disorders not always easy to distinguish: ASD without ID, NLD and ADHD. Our results confirm the importance of examining different domains of visuospatial processing to highlight similarities and differences across these clinical profiles and how stimuli manipulations in terms of perceptual coherence and level of complexity may be usefulness to investigate visuospatial skills. The results obtained allowed us to better explore overlaps and differences among these disorders in relation to a domain not deeply investigated yet and suggested the importance of examining different sub-domains of visuospatial abilities to better differentiate the various neuropsychological profiles.

CHAPTER 5

STUDY IV

Visuo-constructive abilities and visuospatial working memory in ASD-NP and NLD: the role of local bias

5.1 Introduction

As mentioned in previous chapters, studies in the literature have reported similarities between NLD and some profiles of ASD, especially Asperger Syndrome (AS) (DSM-IV TR, APA, 2000), and High-Functioning Autism (HFA) (DSM-5) (e.g. Klin et al., 1995; Rourke, 1995). In particular, some reports have described finding a neuropsychological profile typical of NLD in participants with AS or HFA, with a cognitive profile characterized by normal scores for verbal IQ, and lower scores for perceptual reasoning or performance IQ (Nydén et al., 2010). It should be noted, however, that studies involving larger samples of participants with ASD found a sizable minority of children with ASD who had this neuropsychological profile too (Semrud-Clikeman et al., 2010). When a group of individuals with NLD was compared with a group with AS, a higher verbal IQ and a lower performance IQ (with a difference of more than 15 standard points between them) were found in 74% of the children with NLD and only 37% of those with AS (Semrud-Clikeman et al., 2010). This goes to show that, although some individuals with ASD may have difficulties in measures of visuospatial reasoning, individuals with NLD are clearly more impaired.

Despite these interesting results, very few studies have compared the visuospatial profile of individuals with ASD and NLD. To our knowledge, none have compared the performance of these clinical groups in domains typically impaired in NLD, such as visuo-constructive abilities and visuospatial working memory (VSWM), or explored the possible influence of the coherence of the stimuli on their performance.

The present chapter reviews previous studies conducted on the visuo-constructive abilities and VSWM of children with ASD and NLD, before presenting Study IV of this dissertation. To analyze possible overlaps and differences in the visuospatial profile of these two groups in depth, a subgroup of the participants with ASD but no ID was selected on the grounds of the children's low scores on the Perceptual Reasoning Index (PRI). The aim was to understand whether this subgroup – though not representative of the ASD without ID population as a whole – shared any characteristics with the NLD group in terms of visuo-constructive abilities and VSWM.

5.2 Visuo-constructive abilities and VSWM in ASD and NLD

Visuo-constructive abilities are defined as the skills needed to put parts together to form a single whole (Simic et. al, 2013). These skills are usually assessed by administering tasks in which participants reconstruct a whole figure from a number of different local parts. One of the most popular tasks used to assess these abilities is the block design task (BDT) of the Wechsler Intelligence Scale (WISC, WAIS: Wechsler, 2003, 2008), which involves constructing figures using the sides of cubes. Because of its perceptual properties, this task is usually considered a marker of coherence, assessing not only visuo-constructive abilities, but also their interplay with global-local processing styles. Using modified versions of the BDT, several studies found that individuals with ASD performed better than TD controls in this task, as the former were quicker to reconstruct the figures, especially in the case of participants with HFA (see Happé & Frith, 2006, for a review). Although this result is quite robust, a few studies reported finding no such difference between AS or HFA and TD controls in the BDT (e.g. Altgassen, Kliegel, & Williams, 2005; Ryburn et al., 2009), and participants with AS and HFA in other studies reportedly performed less well than those in the TD control groups (Kaland, Mortensen, & Smith, 2007; Semrud-Clikeman, Fine, & Bledsoe, 2011). Conversely, impairments in visuo-constructive tasks have often been reported in children with NLD, who frequently struggle with tasks requiring the reconstruction of fragments belonging to a whole figure (Mammarella & Cornoldi, 2014). In particular, children with NLD had difficulty with such part-to-whole construction tasks as the Object Assembly subtest (e.g. Drummond et al., 2005), and the BDT of the Wechsler scale (Semrud-Clikeman & Glass, 2008; Venneri, Cornoldi, & Garuti, 2003).

VSWM is a specific working memory component that enables us to temporarily maintain and process visual (e.g., color, shape, texture) and spatial (e.g., an object's location) information for the duration of an ongoing task (Logie, 1995; Mammarella, Borella, Pastore, & Pazzaglia, 2013). How memory functions in ASD is a topic that was neglected for decades (Williams, et al., 2006a), and findings specifically concerning VSWM are inconsistent (Zinke, et al., 2010). Some researchers reported that performance in VSWM tasks was impaired in individuals with ASD, even in those with HFA (Barendse et al., 2013; Corbett, Constantine, Hendren, Rocke, Ozonoff, 2009; Goldberg, et al., 2005; Williams et al., 2006a). This applied, for example, to the Corsi Block-Tapping task (Verté, Geurts, Roeyers, Oosterlaan, & Sergeant, 2006; Williams, Goldstein, Carpenter, & Minshew, 2005), and tasks involving complex spatial working memory demands (Steele, Minshew, Luna, & Sweeney, 2007). Many other studies found no such deficits in these clinical groups, however, even using the same Corsi Block-Tapping task (Ozonoff & Strayer, 2001; Williams et al., 2006b) and other VSWM tasks (Alloway et al., 2009; Geurts et al., 2004; Happé et al., 2006; Mammarella et al., 2014; Sinzig et al., 2008). VSWM was also specifically explored in a series of studies on children with NLD (see Mammarella & Cornoldi, 2014, for a review). The evidence suggested that these children often showed impairments in both simple and complex VSWM storage tasks (Cornoldi et al., 2016). A poor VSWM performance emerged for children with NLD in visual tasks that involved the recall of shapes, colors, and/or textures (Chow & Skuy, 1999; Mammarella & Pazzaglia, 2010), and in spatial tasks requiring the recall of spatial locations and spatial sequences (Chow & Skuy, 1999; Venneri et al., 2003; Mammarella, Lucangeli, & Cornoldi, 2010). By using the Corsi Block-Tapping task to assess VSWM (which involves memorizing a sequence of spatial locations), several studies found that children with NLD had more difficulty than TD children in remembering locations in the backward than in the forward version (e.g. Mammarella & Cornoldi, 2005; Garcia et al., 2014). It was suggested that these deficits in VSWM explain why children with NLD fail in a number of activities (mathematics, drawing, spatial orientation, etc.) believed to involve this visuospatial domain (Cornoldi et al., 1995; Cornoldi, Rigoni, Tressoldi, & Vio, 1999; Cornoldi & Vecchi, 2003).

One task that enables both visuo-constructive abilities and VSWM to be investigated is the Rey-Osterrieth Complex Figure Test (ROCFT; Rey, 1941, 1968), which involves copying a complex figure and then reproducing it from memory a few minutes later. When asked to draw the complex figure, some people begin from its global external elements, indicating their use of a global strategy, others from its local internal elements, which means they use a local strategy (Ropar & Mitchell, 2001). Mixed findings have emerged on administering the ROCFT to participants with ASD. Some authors reported an impaired performance in the recall stage, in which they often showed a disorganized and locally-oriented approach to their drawing (Nydén et al., 2010; Prior & Hoffmann, 1990). But other authors tested participants with ASD, HFA or AS, and found no evidence of any such enhanced local processing, and no differences in overall performance on the ROCFT between these groups and TD children (Jolliffe & Baron-Cohen, 1997; Kuschner et al., 2009; Ropar & Mitchell, 2001). As for children with NLD, previous research indicated that their performance was poor in both the copy and the recall stages of the ROCFT (Gross-Tsur et al., 1995; Semrud-Clikeman, et al. 2010; Semrud-Clikeman, et al. 2011), also by comparison with children with AS or ADHD (Semrud-Clikeman et al., 2010). Thus, children with ASD and NLD may all have difficulties in performing the ROCFT, particularly in the recall stage, but there may be different reasons for their impairments, such as visuospatial deficits (Minshew & Goldstein, 2001), weak planning and organizing skills (Bishop, 1993), information encoding problems (Sohlberg & Mateer, 1989), or difficulties with memorizing material coherently, with a preference for using a local strategy (Prior & Hoffmann, 1990). Further research is needed to better explain their performance.

5.3 Overview of the present study

In the light of previous findings, the present study aimed to investigate visuo-constructive skills and VSWM in a subgroup selected from among the participants with ASD without ID because of their low PRI scores (ASD-NP), and in a group with NLD, comparing them with a matched group of TD controls. The role of local bias in their performance of tasks assessing these two visuospatial domains was also investigated. It is important to emphasize that the ASD-NP group was chosen to shed light on whether or not this subgroup – though not representative of the ASD without

ID population as a whole – shared any characteristics with the NLD group in terms of their visuo-constructive abilities and VSWM. Our participants were presented with a modified version of the BDT used by Caron et al. (2006), which assesses visuo-constructive abilities. This task also enables locally-oriented processing styles to be explored by presenting segmented and unsegmented figures with high or low levels of perceptual cohesiveness (PC). To assess VSWM, an experimental task was used that involved participants having to memorize and then reproduce increasingly difficult configurations with different levels of PC. The copy and recall stages of the ROCFT were also used to assess visuo-constructive abilities and visuospatial memory, respectively. In this task, drawing accuracy was measured with the classic scoring system described in the author's manual (Rey, 1968). The central coherence of the drawing was also examined, based on objective measures obtained using Booth's scoring system (2006).

Our aims were to analyze: 1) similarities or differences in visuo-constructive abilities and VSWM between the performance of participants with ASD-NP, or NLD, and TD controls; and 2) whether the level of PC affected the groups' performance in visuo-constructive and VSWM tasks differently or to the same extent. In other words, we compared the performance of participants with ASD-NP, or NLD, and TD controls in the visuo-constructive BDT, the VSWM task, and the ROCFT, examining whether they had difficulties in the visuo-constructive or VSWM domains. We also explored the role of local bias in their performance, and its involvement in the visuospatial domains examined.

We predicted that the ASD-NP group would perform better than the children with NLD in the BDT, but not necessarily in the ROCFT, for which conflicting results have emerged for children with ASD (Jolliffe & Baron-Cohen, 1997; Kuschner et al., 2009;

Nydén et al., 2010; Prior & Hoffmann, 1990; Ropar & Mitchell, 2001). As for the VSWM task, in light of the results of Study 1 we expect slightly impaired performance for the ASD-NP group, with difficulties in recalling stimuli with high level of cohesiveness and normal performance with stimuli presenting minimum and intermediate levels of cohesiveness, while a poor performance was expected from the NLD group (Mammarella & Cornoldi, 2014). As for the effects of PC, we predicted a weaker detrimental influence of this factor on the ASD-NP group than on the NLD or TD groups, and a more locally-oriented processing in the former, as suggested by previous research (Caron et al., 2006; Happé & Frith, 2006).

A mixed-effects model approach was used to test our research questions (Pinheiro & Bates, 2000). This approach is demonstrated to be effective in dealing with complex data and allows the researcher to simultaneously consider all factors that potentially contribute to the understanding of the structure of the data (Baayen, Davidson, & Bates, 2008). These factors comprise not only the standard fixed-effects factors controlled by the experimenter (in our case, perceptual coherence, condition and group) but also the random-effects factors, in other words, factors whose levels are drawn at random from a population (in our case, participants).

5.4 Method

5.4.1 Participants

The study involved 56 participants: 18 (14 M) individuals with ASD-NP, with a mean full-scale IQ (measured with the WISC III or WISC IV) of 93.39 (SD = 9.54), 18 (13 M) individuals with NLD (mean full-scale IQ = 97.00, SD = 15.31), and 20 (16 M) TD controls (mean full-scale IQ = 98.60, SD = 6.34). The three groups were matched for chronological age [F (2, 53) < 1], gender [χ^2 (df = 2) = .15, p = .93], and full-scale IQ [F (2, 53) = 1.12, p = .33; η^2_p = .04]. A summary of the participants' characteristics is shown in Table 5.1.

All participants were recruited via local community contacts in northeast Italy, at specialized centers for neurodevelopmental disorders, or at local schools (for the TD children). Participants in the ASD-NP group had all received an independent clinical diagnosis of either HFA or AS, according to DSM-IV-TR (APA, 2000) or ICD-10 (WHO, 1992) criteria. They had also scored above the threshold for ASD in the Autism Diagnostic Interview-Revised (ADI-R; Rutter et al., 2005). The same criteria as in Study 1 (Chapter 2) were used to select participants for the ASD-NP group, which consisted of individuals with a PRI up to one standard deviation from the average (between 85 and 113). Participants with ASD-NP were selected from a pool of 50 participants with a diagnosis of AS or HFA whose parents/caregivers consented to their enrolment in this study. Before the experimental materials were administered, the children were screened using the PRI and the vocabulary subtest of the WISC IV or WAIS IV, depending on their chronological age (WISC, WAIS: Wechsler, 2003, 2008). It is worth noting that none of the participants scored less than one standard deviation below the average (<85) in the PRI. Children with ASD-NP were only included in this study if they achieved a standard score of 80 or above for full-scale IQ using the Wechsler Intelligence Scales (WISC IV or WAIS IV: Wechsler, 2003, 2008, depending on the participants' chronological age). All participants with ASD-NP also had scores within normal range ($\geq$7) on the Vocabulary subtest (WISC IV or WAIS IV: Wechsler, 2003, 2008, depending on the participants' chronological age), and were taking no medication.

Participants in the NLD group were diagnosed by private practitioners (child psychiatrists or psychologists) or through the Child Neuropsychiatry Department at the hospital to which they referred. This diagnosis was confirmed by reviewing previous tests consistently with the most recent recommended criteria (Mammarella & Cornoldi, 2014). Participants with NLD showed: (1) a discrepancy between verbal and visuospatial intelligence (with higher scores in the former and lower scores in the latter), as measured with the WISC IV or WAIS IV (Wechsler, 2003, 2008) depending on the chronological age of the participants; (2) difficulties in visuo-constructive tasks, as assessed with the Visual-Motor Integration Test (VMI, Beery, & Buktenica, 2006); (3) impaired social skills, as assessed by interviewing parents, and as suggested by below-average scores on at least two subscales of pragmatics of language included in the parents' form of the Children's Communication Checklist – Second edition (CCC-2; Bishop, 2013); (4) average scores in a word reading task (DDE-2; Sartori, Job, & Tressoldi, 2007), and scores 1 standard deviation (or more) below average in an arithmetical fact retrieval task (depending on the age of the participants, we used: AC-MT 6-11, Cornoldi, Lucangeli, & Bellina, 2012; AC-MT 11-14, Cornoldi & Cazzola, 2004; MT 3 advanced, Cornoldi, Pra Baldi, & Giofrè, 2017).

The TD controls were healthy children of normal intelligence with no history of psychiatric, neurological or neurodevelopmental disorders, who were tested individually at school.

All the children spoke Italian as their first language, and none had any visual or hearing impairments, or any other diagnosed neurological conditions. None of the children in the NLD or TD groups met the criteria for autism using the ADI–R (Rutter et al., 2005). Individuals with ASD-NP or NLD who had comorbid psychopathologies were excluded. A signed informed consent form was obtained from all participants' parents, and the study was approved by the research ethics committee at the University of Padova, Italy.

Table 5.1 Characteristics of the groups with: autism spectrum disorders with no visuospatial peak (ASD-NP), nonverbal learning disorders (NLD), and typical development (TD).

Measures	ASD-NP (n = 18) Mean (SD)	NLD (n = 18) Mean (SD)	TD (n = 20) Mean (SD)	Group significance
Gender (M:F)	14:4	13:5	16:4	N.S.
Age (months)	161.30 (38.48)	148.89 (34.97)	152.50 (44.11)	N.S.
FSIQ[a]	93.39 (9.54)	97.00 (15.31)	98.60 (6.34)	N.S.
PRI[a]	102.11 (6.94)	88.39 (18.83)	103.05 (9.80)	NLD<ASD (*p*=.007), TD (*p*=.003)
ADI-R: A	20.22 (6.22)	5.67 (3.09)	4.60 (2.95)	ASD>NLD, TD (p_s<.001)
ADI-R: B	14.28 (5.43)	3.44 (1.72)	2.80 (1.82)	ASD>NLD, TD (p_s<.001)
ADI-R: C	7.11 (4.17)	1.11 (1.08)	1.00 (1.12)	ASD>NLD, TD (p_s<.001)

Note. [a] Standard scores on the Wechsler Intelligence Scale for Children - Fourth Edition (for participants aged 8 to 16 years) or Wechsler Adult Intelligence Scale - Fourth Edition (for participants from 16 years onwards). FSIQ = Full-Scale Intelligence Quotient; PRI = Perceptual Reasoning Index. ADI-R = Autism Diagnostic Interview-Revised (Rutter et al., 2005): A = Reciprocal Social Interaction, B = Language/Communication, C = Repetitive Behaviors/Interests; high scores on the ADI-R reflect more severe autistic symptoms.

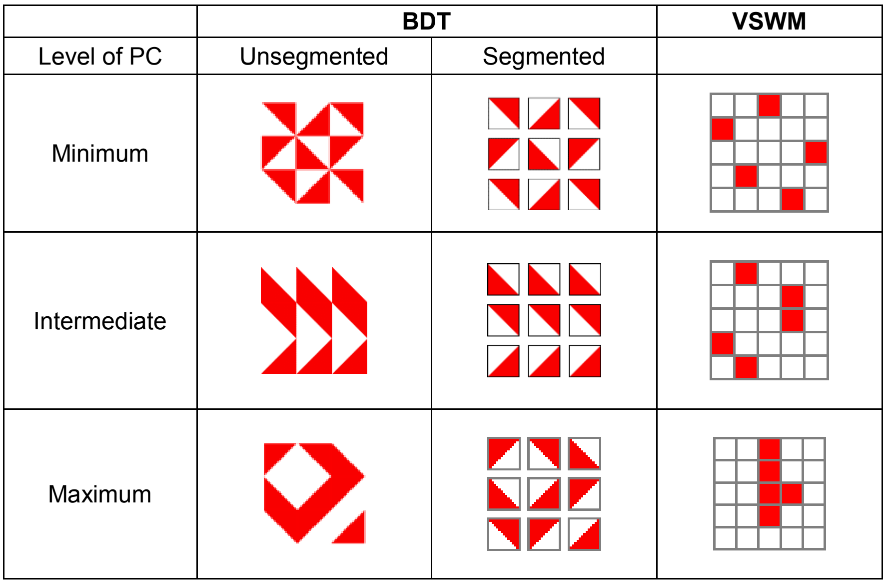
5.4.2 Materials

The modified BDT and the VSWM tasks used in the present study were the same as those used in studies 1 and 3; for clarity, they are also described below.

Modified Block Design Task (BDT)

The Modified BDT (Caron et al., 2006) assesses visuo-constructive abilities and visuospatial processing styles. Participants were shown a two-dimensional red and white geometrical design and then asked to reproduce it by assembling a set of blocks comprising six colored surfaces (two red, two white, two half-red and half-white). The material for this task consisted of 18 items presented in two different conditions: unsegmented and segmented. The items differed in terms of level of PC (minimum, intermediate and maximum), and were balanced for matrix size (4, 9, or 16 blocks). Figure 5.1 shows examples of the stimuli. For each matrix size, a control condition measuring the motor speed component involved in BDT construction was added, in which participants were required to complete as quickly and accurately as possible a monochromic square presented in both the segmented and the unsegmented condition.

Figure 5.1 Examples of stimuli drawn from the BDT (unsegmented and segmented versions) and the VSWMT, presented for three levels of PC (minimum, intermediate and maximum).



Note: BDT: Block Design Task; VSWMT: Visuospatial Working Memory Task; PC: Perceptual Cohesiveness.

The task was administered according to Wechsler's instructions (WISC, Wechsler, 2003). First, the blocks and the book of stimuli were presented. Then an example was shown, which was reconstructed first by the experimenter, and then by the participant. If participants had fully understood the task, the 18 items were presented. Participants were asked to respond as quickly and accurately as possible. A time limit was set for each block configuration, which was 75, 120 and 180 s, for the 4-, 9-, and 16-block designs, respectively (see Cardillo et al., 2017). Performance was timed from the moment the stimulus was placed in front of the participant up until the design was completed or the time limit elapsed. Following the procedure, proposed by Caron et al. (2006), the order of presentation of the trials was identical for all participants and the unsegmented condition was presented before the segmented condition to avoid a facilitation effect. The number of blocks correctly placed on each design was considered to measure accuracy, and response times (RTs, in seconds) were also recorded[5].

Visuospatial working memory task (VSWMT)

The VSWMT is a computerized task for assessing visuospatial working memory (Cardillo et al., under revision). The task consisted of 36 items in the form of white matrixes containing increasing numbers of cells, some of which were red (span: from 4 to 9). Like the BDT, the stimuli were balanced for level of PC (minimum, intermediate and maximum), and each level of PC included two items per span (from 4 to 9). The stimuli with a high level of PC were easy to group into a global configuration and consequently prompted a global processing, whereas the figures with low level of PC were more amenable to being processed locally, by focusing on the different components (Figure 5.1).

[5] In order to control for individual differences in motor speed, the time taken to carry out the control condition was subtracted from the response times of each item. In this way the response times were analysed by controlling for the motor speed of each participant.

Participants were shown a matrix for 3 s, and asked to memorize the configuration. Then, after a .5 s inter-stimulus interval, they were asked to recall the pattern on a completely blank matrix of the same size by using the mouse to mark the red cells previously seen. The order of presentation proceeded from the lower to the higher spans, while a random order was used to present the items within each span. The proportion of cells correctly recalled on each matrix (i.e., number of red cells correctly recalled / total number of red cells) was recorded.

Rey Osterrieth Complex Figure Test (ROCFT)

The Rey-Osterrieth complex figure test (ROCFT; Rey, 1941, 1968) is a neuropsychological test measuring visuo-constructive skills, visuospatial memory and planning. Participants are asked first to copy a complex geometrical figure and then, after an interval of 3 minutes, to reproduce it from memory. The standard scoring system (Rey, 1968) was used to judge the accuracy of the drawings, assigning different scores to each of the 18 elements comprising the figure according to their presence and/or position in a participant's drawing.

The Coherence Index (CI = 0 – 2) was calculated using Booth's method (described by Lopez et al. 2008). The CI was derived by adding the proportion of the total possible scores obtained from the order in which the elements were drawn during the copy and recall trials (the number of global and local elements reproduced in the initial stages of the drawing), and the style defined by the degree of continuity in the drawing process. A high CI score represents a global approach during the drawing, and a continuous (as opposed to fragmented) drawing style for the main elements of the figure. A low CI score represents a local approach and a fragmented drawing style.

5.4.3 PROCEDURE

Participants were tested in a quiet room during two individual sessions lasting approximately 30 minutes each. They were administered the modified BDT (derived by Caron et al. 2006), the VSWMT (Cardillo et al., under revision) and the ROCFT (Rey, 1941, 1968) in counterbalanced order. Instructions were given for each task, and participants practiced with each task before starting the experiment. The VSWMT was administered using a laptop computer with a 15-inch LCD screen, and the experimental procedure was programmed with the E-Prime software (Schneider, Eschman, & Zuccolotto, 2002).

For the BDT and VSWMT, the stimuli were prepared with different levels of PC, which is a global property of the figures that can be manipulated by varying the number of "adjacencies" of opposite-colored edges between the blocks/cells (Caron et al., 2006). A given figure could have a minimum level of PC (many edge cues and adjacencies of opposite-colored blocks/cells, forming local configurations), an intermediate level of PC (half the blocks/cells comprising the figure had adjacencies with opposite-colored blocks/cells, and the other half had adjacencies with same-color blocks/cells), or a maximum level of PC (the blocks/cells had adjacencies with others of the same color, forming global configurations) (see Figure 5.1).

5.5 RESULTS

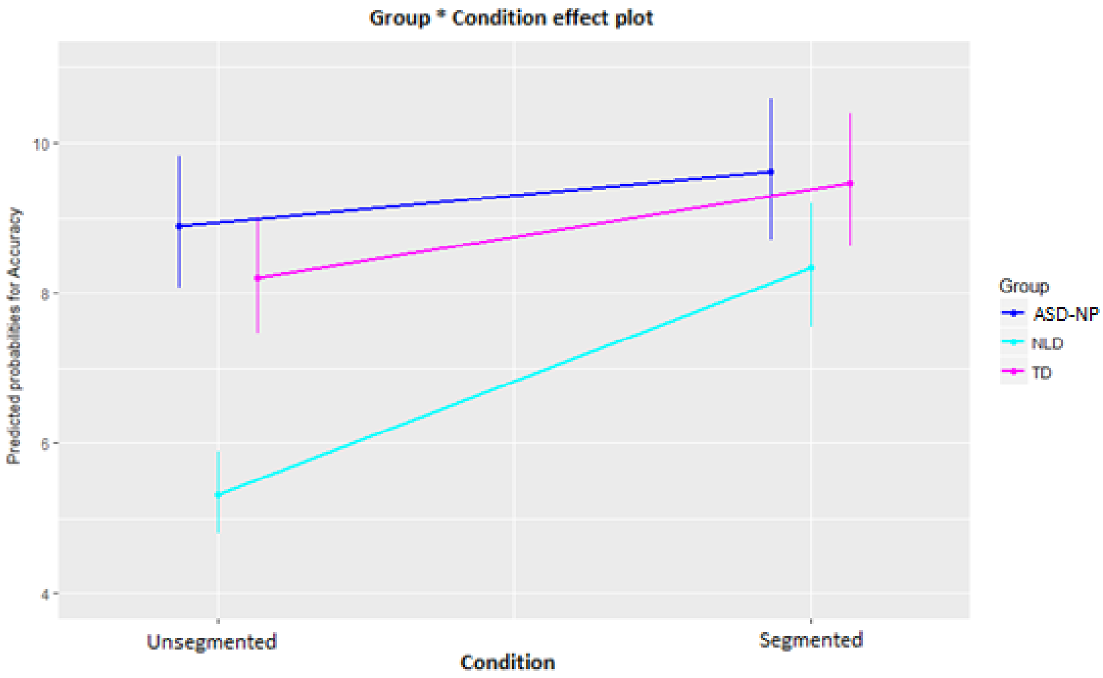
Data analyses: Data analyses were conducted using R (R Core Team, 2015). The accuracy data obtained with the BDT and VSWMT were analyzed using a mixed-effects modelling approach and the "lme4" package (Bates et al., 2015) with the function family as "Poisson" and "Binomial" respectively. The Response Times (*RT*s) for correct answers (in seconds) were analyzed for the BDT, adopting a generalized linear mixed approach with the function family as “Gamma”, and the link as “log”. Data obtained from the ROCFT were fitted with a linear regression model using the “lm” function.

The following fixed effects and their interactions were tested for BDT and VSWMT: Group (with 3 levels: ASD-NP, NLD, TD) and level of PC (with 3 levels: Minimum, Intermediate, Maximum). The fixed effect of Condition (with 2 levels: Segmented, Unsegmented) was also considered for BDT. The fixed effect of Group (with 3 levels: ASD-NP, NLD, TD) was tested for the ROCFT. Participants were included as random effects to consider their variability in each mixed-effect model. The significance of both fixed and random effects was examined by means of a series of likelihood ratio tests for nested models based on the chi-square distribution (Pinheiro & Bates, 2000). The Akaike Information Criterion (AIC; Akaike, 1974) was also recorded for each model (a lower AIC indicates a better model). Graphical effects were obtained using the “sjplot” package (Lüdecke & Schwemmer, 2017).

BDT – Accuracy. A significant main effect of Group emerged [$\chi 2(2) = 19.10$, $p < .001$ (full model: $AIC = 13602$; model without Group: AIC = 13617)]. The model coefficients showed that the NLD group was less accurate than the other groups (p_s<.001), while no other differences between the groups came to light.

The main effect of Condition was significant [$\chi 2(1) = 171.36$, $p < .001$ (model without Condition: $AIC = 13771$)]. The model coefficients showed that participants performed better in the segmented than in the unsegmented condition ($p <.001$). The main effect of the level of PC was significant too [$\chi 2(2) = 37.11$, $p < .001$ (model without PC: $AIC = 13635$)]. The model coefficients showed that participants performed better on the minimum PC level than on the intermediate ($p = .003$) or maximum levels (p<.001), and they were more accurate on the intermediate than on the maximum level of PC (p = .002). The analysis revealed a significant interaction between Group and Condition (see Figure 5.2), [$\chi 2(2) = 97.37$, $p < .001$ (model with Interaction: *AIC* = 13508)]. For the unsegmented condition, the model coefficients showed that the NLD group was less accurate than either of the other groups (p_s<.001), while no differences emerged between the ASD-NP and TD groups. For the segmented condition, the model coefficients showed that the NLD group was less accurate than the ASD-NP group (p = .003), while no other differences emerged.

Figure 5.2 Predicted probabilities for accuracy by Group and Condition in the BDT. Error bars represent 95% confidence intervals.

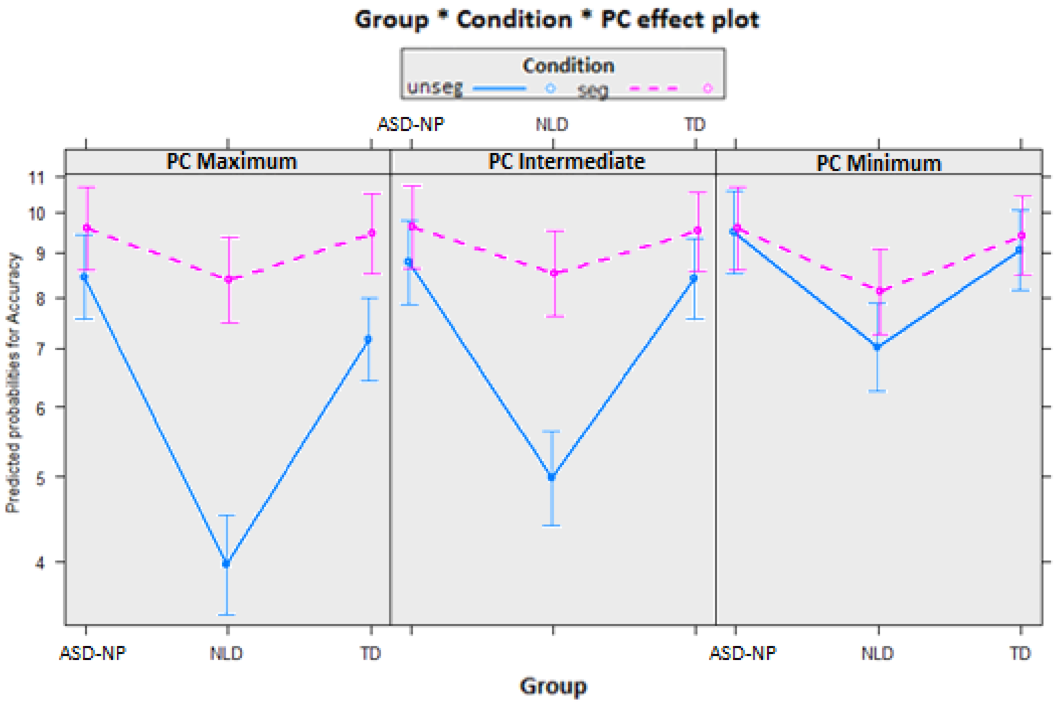


The interaction between Condition and Level of PC was also significant [$\chi 2(2)$ = 55.9, p < .001 (model with Interaction: *AIC* = 13550)]. The model coefficients showed that, in the unsegmented condition, participants were more accurate when responding on the minimum level of PC than on the intermediate or maximum levels

(p_s<.001), and they were more accurate on the intermediate than on the maximum level ($p < .001$). No differences emerged between the levels of PC in the segmented condition. The interaction between Group and Level of PC was significant too [$\chi 2(4) = 10.59$, $p = .03$ (model with Interaction: *AIC* = 13599)]. The model coefficients showed that the group with NLD performed better on the minimum PC level than on the intermediate ($p = .001$) or maximum levels (p<.001), with no significant differences between the intermediate and maximum levels; the TD group performed better on the minimum PC level than on the maximum level ($p < .001$), with no other significant differences between the PC levels; and the ASD-NP group did not show any significant differences between the levels of PC.

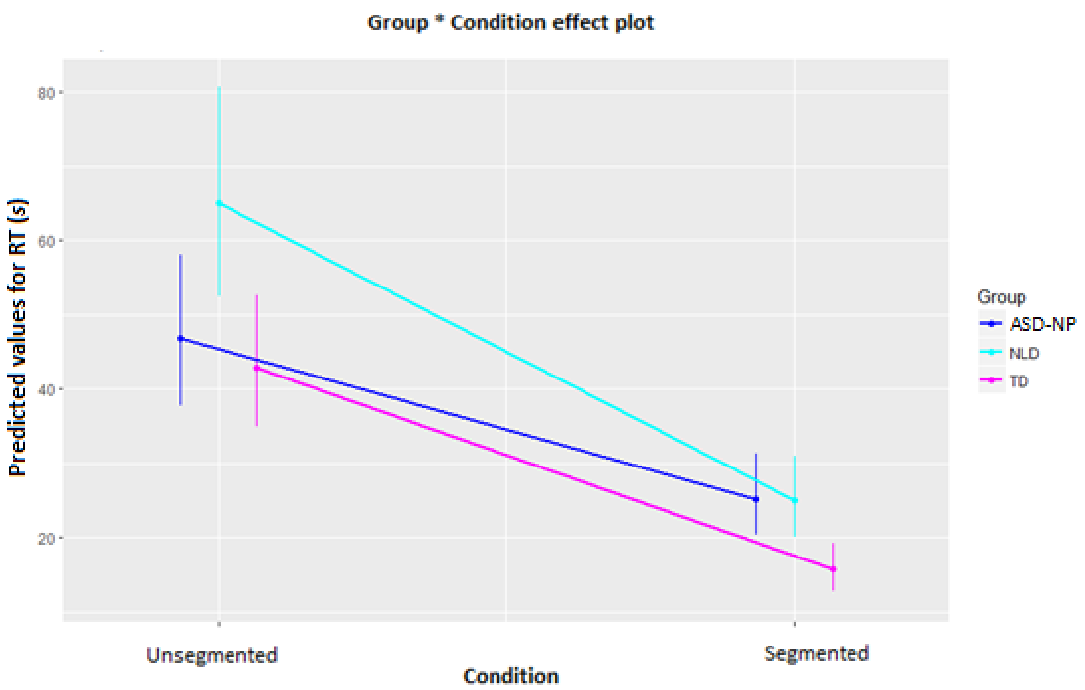
Finally, the interaction between Group, Condition and Level of PC was significant [$\chi 2(4) = 28.65$, $p < .001$ (model without Interaction: *AIC* = 13450; model with Interaction: *AIC* = 13429)] (see Figure 5.3). In the unsegmented condition the NLD group was less accurate than the other groups for all the PC levels (p_s<.001). In the segmented condition, on the other hand, the NLD group's performance was only less accurate than the ASD-NP group's for the minimum PC level ($p = .004$). No other differences emerged between the groups. The performance of the group with ASD-NP was only less accurate in the unsegmented than in the segmented condition for the maximum level of PC ($p = .004$); the TD group's performance was less accurate in the unsegmented than in the segmented condition for the minimum and intermediate levels of PC ($p_s \leq .003$); and the NLD group's performance was less accurate in the unsegmented than in the segmented condition for all levels of PC ($p_s \leq .003$).

Figure 5.3 Predicted probabilities for accuracy by Group, Condition and PC in the BDT. Error bars represent 95% confidence intervals.



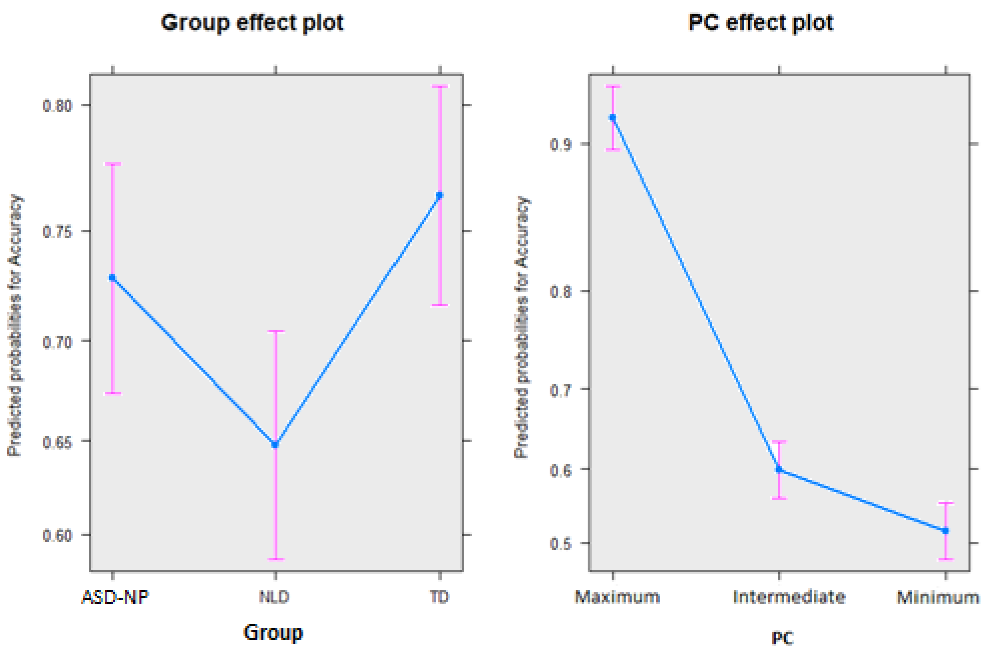
BDT – Response Times (RTs). A significant main effect of Group emerged [$\chi2(2) = 8.85$, $p = .01$ (full model: *AIC* = 18211; model without Group: AIC = 18216)]. The model coefficients showed that the NLD ($p = .002$) and the ASD-NP ($p = .05$) groups were slower than the TD group, while no other differences between the groups came to light. The main effect of Condition was significant [$\chi2(1) = 419.58$, $p < .001$ (model without Condition: *AIC* = 18628)]. The model coefficients showed that participants completed the task in the unsegmented condition more slowly than in the segmented condition ($p <.001$). The main effect of the level of PC was significant too [$\chi2(2) = 54.67$, $p < .001$ (model without PC: *AIC* = 18261)]. The model coefficients showed that participants completed the task faster on the minimum PC level than on the intermediate or maximum levels ($p_s<.001$), and they were faster on the intermediate than on the maximum level of PC ($p < .001$). The analysis revealed a significant interaction between Group and Condition (see Figure 5.4), [$\chi2(2) = 18.73$, $p < .001$ (model with Interaction: *AIC* = 18196)]. For the unsegmented condition, the model coefficients showed that the NLD group was slower than the ASD-NP (p=.003) or TD (p<.001) groups. For the segmented condition, the ASD-NP and NLD groups were both slower than the TD group (p_s=.04), with no difference between the former two. The interaction between Condition and Level of PC was also significant [$\chi 2(2)$ = 40.13, p < .001 (model with Interaction: AIC = 18175)]. The model coefficients showed that, in the unsegmented condition, participants were quicker to respond on the minimum level of PC than on the intermediate or maximum levels (p_s<.001), and they were faster on the intermediate than on the maximum level (p < .001). No such differences emerged between the levels of PC in the segmented condition. Finally, the interaction between Group and Level of PC was not significant [$\chi 2(4)$ = 8.09, p = .09 (model with Interaction: AIC = 18211)], nor was the interaction between Group, Condition and Level of PC [$\chi 2(4)$ = 2.77, p = .60 (model without Interaction: AIC = 18161; model with Interaction: AIC = 18166)].

Figure 5.4 Predicted values for response times (*sec.*) by Group and Condition in the BDT. Error bars represent 95% confidence intervals.



VSWMT. A significant main effect of Group was found (see Figure 5.5) [$\chi 2(2) = 9.14$, $p = .01$ (full model: AIC = 6344.4; model without Group: *AIC* = 6349.6)]. The model coefficients showed that the NLD group was less accurate than either of the others (p_s <.04). No other differences emerged between the groups. There was also a main effect of PC (see Figure 5.5) [$\chi 2(2) = 1960.8$, $p < .001$ (model without PC: *AIC* = 8301.2)]. The model coefficients showed that participants recalled stimuli better if they were characterized by a maximum PC than when the levels of PC were intermediate or minimum (p_s<.001), and their recall was better for intermediate than for minimum PC levels (p<.001). Finally, the interaction between Group and Level of PC was not significant [$\chi 2(4) = 3.52$, $p = .47$ (model with Interaction: *AIC* = 6348.9)].

Figure 5.5 Predicted probabilities for accuracy by Group and by PC in the VSWMT. Error bars represent 95% confidence intervals.



ROCFT. As regards copying accuracy, a main effect of Group emerged [$F(2, 53) = 10.52$, $p < .001$; *adjusted* $R^2 = .26$]. The NLD group had worse scores than the TD ($p < .001$) or ASD-NP ($p = .005$) groups. No other significant differences emerged. A main effect of Group also emerged for recall accuracy [$F(2, 53) = 4.65$, $p = .01$; *adjusted* $R^2 = .12$]. Both the NLD ($p = .007$) and the ASD-NP ($p = .02$) groups had worse scores than the TD group. No other significant differences emerged. As for the coherence index (CI), no main effect of Group emerged for the copying condition [$F(2, 53) = 2.87$, $p = .07$; *adjusted* $R^2 = .06$], while in the recall condition there was a main effect of Group [$F(2, 53) = 3.22$, $p = .05$; *adjusted* $R^2 = .07$]. The ASD-NP group had a lower CI than the TD controls ($p = .02$), while there were no other differences between the groups.

5.6 Discussion

The main aim of the present study was to investigate visuo-constructive skills and VSWM in a subgroup of participants with ASD-NP and a group with NLD, comparing them with a TD group matched for age, gender and full-scale IQ. Another aim was to assess the influence of local bias, to see whether the level of PC affected participants' performance in the visuospatial domains examined to a different or the same extent.

A modified BDT was used to assess visuo-constructive abilities and local vs global processing styles. Based on generalized mixed-effects models, our results revealed an impaired performance in the NLD group, particularly for the unsegmented condition, in which they were less accurate and slower than the other groups across all PC levels. In the segmented condition, the children with NLD were again slower than the TD controls, showing (as in previous studies) a general weakness in the visuo-constructive domain (Mammarella & Cornoldi, 2014; Semrud-Clikeman & Glass, 2008; Venneri et al., 2003). Participants with ASD-NP, on the other hand, performed normally in terms of accuracy, showing no differences vis-à-vis the TD controls – a finding consistent with previous reports (Altgassen et al., 2005; Ryburn et al., 2009). But, differently from other two groups no differences in accuracy between the various PC levels emerged for the ASD-NP group, i.e. they were less sensitive to perceptual cohesiveness in the visuo-constructive domain (Caron et al., 2006; Happé & Frith, 2006; Mottron et al., 2003). As concerns response times in the BDT, the ASD-NP group was slower than the TD group, in line with the results of our first study (Chapter 2), but only in the segmented condition.

Regarding VSWM, the NLD group's performance was, here again, impaired across all levels of PC, confirming that the neuropsychological profile of this group is characterized by a poor VSWM irrespective of the coherence of the stimuli (Mammarella & Cornoldi, 2014), especially in spatial tasks that require the recall of spatial locations (Chow & Skuy, 1999; Venneri et al., 2003; Mammarella et al., 2010). On the other hand, no deficits emerged for the ASD-NP group vis-à-vis the TD controls, indicating that VSWM is not a characteristic weakness in the cognitive domain of individuals with ASD-NP (Alloway et al., 2009; Geurts et al., 2004; Happé et al., 2006; Ozonoff & Strayer, 2001; Sinzig et al., 2008; Williams et al., 2006b). When the effect of PC was considered in the VSWMT, all three groups were more accurate in recalling stimuli with a higher level of cohesion (characterized by global configurations). In other words, the participants with ASD-NP and NLD, like the TD controls, benefited more from being presented with global rather than local stimuli, confirming that the former are easier to remember than the latter (Brown, Forbes, & McConnell, 2006; Brown & Wesley, 2013; Riby & Orme, 2013).

Finally, consistently with previous studies (Gross-Tsur et al., 1995; Semrud-Clikeman, et al. 2010; Semrud-Clikeman, et al. 2011), participants with NLD performed poorly in both copying and recalling the ROCFT, confirming their impairment in the visuo-constructive and VSWM domains. This group also obtained a similar coherence index to that of typical development. In the ROCFT the ASD-NP group was less accurate than the TD group when it came to recall, but not when copying the figure. This impaired performance in the memory task of the ROCFT seems to contrast with the results of the VSWMT, in which the ASD-NP group was comparable with the TD group. Analyzing the cognitive processes involved in the two tasks might help us to clarify this particular impairment in the ASD-NP children's recall in the ROCFT: unlike the VSWMT (which involves remembering the position of each square in a matrix), the ROCFT demands visuo-constructive skills as well as VSWM. The result obtained in the recall stage of the ROCFT can be further clarified if we look at the coherence index of the drawings: in the recall stage the ASD-NP group's drawings featured a low coherence, revealing a greater focus on detail and a fragmented drawing style, whereas the TD group used a more global approach. A reasonable explanation for the ASD-NP group's poor recall in the ROCFT could thus relate to the influence of local bias: focusing on details rather than on global features would adversely affect their recall performance (Lopez et al. 2008). So, here again, local bias affected the performance of participants with ASD-NP in tasks demanding visuo-constructive skills specifically to combine parts to form a single whole (Simic et al., 2013).

To sum up, our findings enabled us to clearly differentiate the visuospatial profile of children with NLD from that of children with ASD-NP. The NLD group's performance was impaired in all the domains examined across all the PC levels, so their visuospatial deficit affected their performance at both local and global levels of processing. The ASD-NP group had a heterogeneous visuospatial profile, with strengths and weaknesses, and different effects of local bias depending on the domain considered. Their performance was normal in terms of VSWM, as they took advantage of being presented with global rather than local stimuli (Navon, 1977). In the visuo-constructive domain, the ASD-NP group had longer response times than the TD group, but only in the segmented condition of the BDT, and they fared worse than the TD controls in the recall stage of the ROCFT. Although this latter result seems in conflict with the results of the VSWMT, a reasonable explanation for the ASD-NP group's poor recall in the ROCFT could relate to the influence of local bias. The analysis of CI seemed to confirm this hypothesis: participants with ASD-NP had a lower coherence index, indicating that focusing on details rather than on global features would adversely affect memory performance (Lopez et al. 2008).

Further studies are needed, however, to confirm and extend our results, and to overcome the limitations of the present study. One such limitation lies in the criteria used to select the ASD-NP group, which had a PRI within one standard deviation from the average. We had initially planned to involve participants with ASD and lower scores on the PRI, possibly matching those of the NLD group, but it proved difficult to find participants with ASD but no ID who had such low scores for perceptual reasoning. Previous studies had also found that only a sizable minority of children with AS or HFA had this neuropsychological profile (Semrud-Clikeman et al., 2010), supporting the hypothesis that HFA and NLD can be distinguished. Future research should nonetheless try to overcome this limitation and include participants who have ASD without ID matched with NLD for PRI scores (even if they are not representative of the whole spectrum), in order to analyze similarities and differences between NLD and ASD in more depth. Another limitation of this study concerns the small size of our samples. Further research should strive to involve a larger number of participants. The use of different methods to calculate local bias in the tasks administered is also a limitation of our work. In fact, the PC of the stimuli was used to manipulate the local and global presentation of the images for the visuo-constructive BDT and VSWMT, while the CI was calculated for the ROCFT. In future studies, it would be helpful to devise new tasks for assessing global-local processing, and to develop shared scoring procedures.

In conclusion, despite the above-mentioned limitations, we believe the present study sheds more light on the visuospatial profile of ASD and NLD, two neurodevelopmental disorders characterized by some overlapping symptoms which pose a challenge for their diagnosis (Williams et al., 2008). Examining different visuospatial domains by using various tasks revealed similarities and differences between these disorders. Manipulating the coherence of the stimuli enabled us to better interpret the results obtained, particularly for the ASD-NP group, suggesting that global-local processing styles are a key research issue in the field of ASD.

Although our findings suggested that NLD and ASD are different disorders, we cannot exclude the possible comorbidity between them. In other words, our findings do not allow us the possibility to exclude the possible presence of visuospatial difficulties in children with ASD, or the presence of social difficulties in children with NLD (which were not studied in these studies). Thus, future studies should try to disentangle this issues.

CHAPTER 6

GENERAL DISCUSSION

Visuospatial ability is one of the several human cognitive competences considered essential in our daily interaction with the environment (Hegarty & Waller, 2005; Jansen et al., 2010). Several studies have demonstrated the vital role of visuospatial abilities in numerous activities, such as recognizing and manipulating objects, reproducing drawings, recalling locations, mental imagery and academic achievement, to name just a few (Tzuriel & Egozi, 2010). A useful way to approach the neuropsychological domain of visuospatial abilities is with the global-local paradigm, which enables important information to be obtained about the visual processing strategies individuals use when they look at a scene or have to solve visuospatial tasks (Roalf et al., 2006). When individuals attend an event, for instance, they may use a global processing style and consider the gestalt of a set of stimuli, or a local processing style, focusing on details (Förster & Dannenberg, 2010; Navon, 1977; Schooler, 2002).

An abundance of research on global versus local processing has revealed preferential processing styles (with a global or local bias) in specific neurodevelopmental disorders, particularly as concerns Autism Spectrum Disorders (ASD) (Caron et al., 2006; Kuschner et al., 2009). A diminished sensitivity to perceptual cohesiveness, and a locally-oriented processing of visuospatial material is reportedly characteristic of the cognitive profile of individuals with ASD (Caron et al., 2006; Happé & Frith, 2006; Mottron et al., 2003). Conflicting findings have often emerged in the literature (see for example Van der Hallen et al., 2015), however, prompting some authors to rethink the concept of 'local processors' often applied to individuals with ASD (D'Souza et al., 2016). This approach derived from evidence of individuals with different developmental disorders being able to process both local and global information, depending on the task and the cognitive domain involved, but they do so in atypical ways (Dukette & Stiles, 2001). Cross-task and cross-syndrome comparisons have consequently been suggested as the best way to analyze these processing abilities, and reveal similarities and differences in global-local processing styles specific to certain neurodevelopmental disorders (D'Souza et al., 2016).

The effects of perceptual cohesiveness and global or local processing styles have never been studied in children with Nonverbal Learning Disabilities (NLD), even though this distinction has proved important in elucidating the perceptual difficulties associated with other, related developmental disabilities (e.g. Happé, 1999). There is evidence to suggest that the issue could be relevant in the case of NLD as well, since a poor performance in gestalt configuration tasks and in reversing ambiguous figures, for instance, has been observed in children with NLD (Chow & Skuy, 1999; Mammarella & Pazzaglia, 2010).

The present PhD dissertation aimed to improve our understanding of the role of global-local visuospatial processing in the neuropsychological profile of specific neurodevelopmental disorders, using cross-task and cross-disorder comparisons. Children with ASD without intellectual disability (ID) or NLD were investigated in terms of their performance in different domains of visuospatial skills, comparing them with each other and with children who had other neurodevelopmental disorders, such as dyslexia or Attention Deficit Hyperactivity Disorder (ADHD). The assessment focused on visuospatial processing speed, visuo-perceptual and visuo-constructive abilities, visuospatial working memory (VSWM), and their interplay with local and global processing. Using a modified Block Design Task (BDT) paradigm (Caron et al., 2006), four different studies were conducted to examine global and local visuospatial processing. One was a cross-task comparison on different visuospatial domains with two groups of participants with ASD without ID, one with and the other without a visuospatial peak (Study I, Chapter 2). A second study involved participants with symptoms of NLD and dyslexia (Study II, Chapter 3) in an effort to identify strengths and weaknesses in their visuospatial profiles. A third study (Chapter 4) applied the same experimental method to a cross-disorder comparison between children with ASD without ID, NLD or ADHD to seek similarities and differences in their visuospatial processing. Visuo-constructive abilities and VSWM were also investigated, comparing a subgroup of the participants with ASD without ID who had low Perceptual Reasoning Index (PRI) scores with the participants with NLD to see whether or not this subgroup of ASD – though not representative of the ASD without ID population – resembled the NLD group in the domains examined (Study IV, Chapter 5).

The main findings of each study are summarized in the following sections. The strengths and limitations of the studies are also mentioned, as are the questions that remain open and suggestions for further research. The clinical and educational implications of the study findings are also discussed.

6.1 Research findings Overview

The results of Study I demonstrate the value of a cross-task comparison on different visuospatial processes in children with ASD, showing how important it is to take specific methodological factors into account. Considering the role of perceptual reasoning abilities with the aid of well-operationalized tasks inspired by the BDT helped us to clarify the visuospatial profile of individuals with ASD. Different results emerged for those with and without a visuospatial peak (-P and -NP) when they were compared with matched typically-developing individuals on processing speed, visuo-perceptual and visuo-constructive tasks, and VSWM. While participants with ASD-NP performed poorly in all domains, revealing weaker spatial integration abilities in the visuo-perceptual domain and a diminished sensitivity to perceptual coherence in VSWM tasks, the ASD-P group used both global and local processing effectively for the task in hand, and a local bias only emerged in the visuo-constructive task. These results support the conviction that the use of a local or global processing style by individuals with ASD can vary, depending not only on the requirements of the task, but also on the cognitive domain involved (Dukette & Stiles, 2001). So simply labelling them as "local processors" is restrictive (D'Souza et al., 2016) because specific factors might influence their performance, such as their cognitive visuospatial functioning and the different domains examined by a task.

Study II confirmed the importance of examining visuospatial processes, and the utility of the different versions of the BDT in distinguishing between global and local processing modalities in other neurodevelopmental disorders too. In fact, the results showed that children with symptoms of NLD were less accurate in visuo-constructive tasks, while children with symptoms of dyslexia were only slightly impaired in a visuo-constructive task, but clearly slower in the perceptual task. The manipulation devised to compare global and local configurations particularly affected the performance of children with symptoms of NLD, crucially showing that they were less able to benefit from different levels of cohesiveness and found it more difficult to deal with different levels of complexity, probably as a consequence of their less flexible and efficient visuospatial processes (Mammarella & Cornoldi, 2005). In particular, the global dominance mechanism (Navon, 1977) made it more complicated for the group with symptoms of NLD to switch from a global to a local processing of the stimuli, which was needed to complete the visuo-constructive task correctly.

In the light of the results that emerged from the first two studies, in which the issue of global-local processing was examined separately for ASD without ID and for NLD, and bearing in mind that some symptoms of these disorders overlap (Williams et al., 2008), the aim of Study III was to draw a cross-disorders comparison of participants' global-local visuospatial processing, highlighting similarities and differences across three clinical profiles - ASD without ID, NLD and ADHD - as compared with typical developing (TD) controls. Our results revealed different visuospatial profiles for the groups considered, and suggested the utility of manipulating the coherence of stimuli to investigate visuospatial skills. The group with NLD showed a marked deficit in all the visuospatial domains examined by comparison with the other groups, confirming that impairments in the visuospatial domain are a distinctive, core issue in this disorder (Cornoldi et al., 2016; Semrud-Clikeman et al., 2010). An impairment in most domains emerged across all the levels of coherence, indicating that their visuospatial deficit affected their local and global processing performance. As for the visuo-perceptual domain, the group with NLD also had difficulty integrating local configurations form a coherent whole. A variable profile emerged for the visuospatial abilities of children with ADHD, who were found impaired (as in previous studies) in visuospatial processing speed and VSWM (Martinussen et al., 2005; Weigard & Huang-Pollock, 2017). These participants also had some difficulties in visuo-constructive tasks that involved dealing with global configurations, but not if local configurations were needed, while their visuo-perceptual abilities were normal. Participants with ASD had a typical performance in all the domains examined, using both global and local visuospatial processes effectively. The sole exception concerned the visuo-constructive task, in which this group had slower response times and proved less sensitive to perceptual coherence (Caron et al., 2006; Shah & Frith, 1993).

Finally, since individuals with NLD and those with high-functioning autism or Asperger Syndrome (DSM-IV TR, APA, 2000) are often confused, Study IV included a further comparison between ASD and NLD, involving a subgroup of the participants with ASD without ID who had no peak on PRI (ASD-NP). Once again, our results enabled us to clearly differentiate the visuospatial profile of children with NLD from that of children with ASD-NP. Consistently with previous research (see Mammarella & Cornoldi, 2014 for a review), and with our Study III, the former group showed an impaired performance in all the domains examined across all the levels of coherence, their visuospatial deficit affecting both local and global levels of processing. The ASD-NP group had a more heterogeneous visuospatial profile, with strengths and weaknesses, and a variable effect of local bias, depending on the domain considered. These participants performed normally in VSWM, taking advantage of the presentation of global rather than local stimuli - consistently with the global dominance hypothesis (Navon, 1977). Differences vis-à-vis the TD children emerged for the visuo-constructive domain: the ASD-NP group had slower response times in the segmented condition of the BDT, and fared worse than the TD controls in the recall stage of the Rey Osterrieth Complex Figure Test (ROCFT). This latter result seems to contrast with the results of the VSWM task, in which participants with ASD were comparable with the TD group. A reasonable explanation for the ASD group's poor recall in the ROCFT may relate to the influence of local bias: focusing on details rather than on global features would adversely affect memory performance (Lopez et al. 2008). Analyzing the coherence index (CI) seemed to confirm this hypothesis: a low CI emerged for participants with ASD, indicating that they focused more on details and had a more fragmented drawing style, whereas the TD group used a global approach when drawing the figures. Here again, local bias affected the performance of participants with ASD in tasks demanding visuo-constructive skills that specifically involved combining parts to form a single whole (Simic et al., 2013).

Table 6.1 summarizes the main findings of the four studies carried out for the present PhD dissertation.

Although clear differences emerged among the clinical groups involved in our studies, it is important to note also some similarities, going beyond the diagnostic boundaries set out in the traditional categorical psychiatric approach. By comparing the results obtained across our studies, similarities in the performance of participants with NLD and participants with ASD-NP and ADHD emerged. Both NLD and ASD-NP showed impaired performance in drawing from memory a complex figure (recall stage of the ROCFT), a task demanding visuo-constructive skills as well as VSWM. In addition both groups showed slower response times than the TD group in the segmented condition of the visuo-constructive BDT. Furthermore both participants with NLD and ADHD showed difficulties in performing a visuospatial processing speed task, with performance slower and less accurate than the TD group. Finally, similar difficulties emerged for these latter two groups in a visuospatial working memory task, albeit with different levels of impairment. Overall, the results of our studies are more compatible with a dimensional approach (DSM-5, 2013) considering for a single individual the functioning along different dimensions, than with the traditional categorical psychiatric approach. According to the dimensional approach, the boundaries between many neurodevelopmental disorder "categories" are fluid over the life course, and many symptoms assigned to a single disorder may occur, at varying levels of severity, in many other disorders (Annaz, Karmiloff-Smith, & Thomas, 2008; Thomas, et al. 2009).

Based on this summary, the following points outline the new information contributed to the study of certain neurodevelopmental disorders.

a. In agreement with D'Souza and coauthors (2016), our results support the conviction that labelling individuals with ASD as 'local processors' is restrictive. They may use both local and global processing styles, depending on the demands of the task in hand, the visuospatial domain involved, and their cognitive functioning.
b. Analyzing global-local processing in children with ASD without ID showed that a local bias often affected their performance in visuo-constructive tasks that specifically involved combining parts to form a single whole.
c. Although the DSM 5 (APA, 2013) recommends using a single label for ASD, it is always important to bear the dimensional spectrum concept in mind. As demonstrated by the results discussed in the present dissertation, studying individual differences in ASD can provide crucial insight on the cognitive strengths and weaknesses associated with the condition.
d. Analyzing visuospatial abilities clearly distinguished between the neuropsychological profiles of children with ASD without ID and cases of NLD: children with NLD performed less well than children with ASD in all domains, with both global and local stimuli. It is worth noting that

global-local processing *per se* enabled a distinction between ASD without ID and NLD when it came to drawing a complex figure from memory.

e. Children with dyslexia and ADHD, who were involved as controls in our studies, revealed some impairments in the visuospatial tasks administered, that were consistent with their clinical profiles. Children with dyslexia had a slight difficulty with complex materials in the visuo-constructive task (Morris et al., 1998; Winner et al., 2001), and a processing speed deficit (Shanahan et al., 2006), whereas children with ADHD were impaired mainly in terms of visuospatial processing speed and visuospatial working memory (Martinussen et al. 2005; Shanahan et al., 2006; Vance et al. 2007; Willcutt et al. 2005), while they had slight difficulties in visuo-constructive tasks, probably due to their attention problems.
f. Although clear differences between groups were found in our studies, some similarities were highlighted among the performance of the clinical groups, with particular reference to NLD, ASD-NP and ADHD. These results do not allow us to exclude a possible comorbidity among the disorders. Therefore, it could be concluded that these neurodevelopmental disorders represent different conditions that could coexist in some cases.

Table 6.1 Summary of the essential information concerning each study: number of participants (N), groups involved, visuospatial domains examined, main aims, and findings.

Study	N	Groups	VS domain	Aims	Main findings
I	77	ASD-P ASD-NP TD-P TD-NP	VPST Visuo-perceptual Visuo-constructive VSWM	• Analyzing strengths and weaknesses in the visuospatial profile of each ASD group, considering the role of their PRI level; • Investigating whether local/global processing differently affects each domain (D'Souza et al., 2016).	• ASD-NP: poor overall performance; weaker spatial integration abilities in the visuo-perceptual domain; diminished sensitivity to perceptual coherence in VSWM; • ASD-P: effective use of global and local processing; local bias in the visuo-constructive domain.
II	60	NLD S. Dyslexia S. TD	Visuo-perceptual Visuo-constructive	• Exploring whether children with NLD or dyslexia have specific impairments in the two domains; • Analyzing the use of global/local processing styles and seeing whether it affects the children's performance differently.	• NLD: performance poor in the visuo-constructive task, and poorer still in the use of visuospatial global/local processes; • Dyslexia: slightly impaired in the visuo-constructive task, slower in the perceptual task.
III	193	ASD NLD ADHD TD	VSPS Visuo-perceptual Visuo-constructive VSWM	• Highlighting similarities and differences between the groups, identifying their strengths and weaknesses by domain; • Analyzing the role of global/local processing style, exploring whether it affects the groups' performance in the tasks differently or to the same extent.	• NLD: marked deficit in all domains at local and global processing levels; difficulty in integrating local configurations in the visuo-perceptual domain. • ADHD: normal visuo-perceptual abilities, impairments in VSPS and VSWM, slight difficulties in the visuo-constructive domain. • ASD: normal performance in all domains, effective use of global and local processing; slower RTs and a diminished sensitivity to perceptual coherence in the visuo-constructive task.
IV	56	ASD-NP NLD TD	Visuo-constructive Visuomotor VSWM	• Examining the existence of possible overlaps between ASD-NP and NLD in the three domains; • Highlighting the influence of local bias on participants' performance, depending on the domain.	• NLD: impaired performance in all domains and across all processing levels; • ASD-NP: normal accuracy in VSWM and visuo-constructive tasks, and in copying a complex figure; slower RTs in the visuo-constructive task, poor performance and low coherence in drawing a figure from memory.

Note: ASD-P: Autism spectrum disorders with visuospatial peak; ASD-NP: Autism spectrum disorders without visuospatial peak; TD-P: Typical development with visuospatial peak; TD-NP: Typical development without visuospatial peak; NLD S: Symptoms of nonverbal learning disabilities; Dyslexia S: Symptoms of dyslexia; NLD: Nonverbal learning disabilities; ADHD: Attention deficit hyperactivity disorder; VPST: Visuospatial processing speed task; VSWM: Visuospatial working memory; PRI: Perceptual reasoning index.

6.2 Study Limitations and Suggestion for Future Research

Although the present dissertation offers novel evidence and underscores the utility of applying a well-operationalized paradigm to the study of visuospatial global-local processing in neurodevelopmental disorders, some limitations need to be mentioned, and a number of other aspects might be addressed in future research. While some of the issues were presented in the Discussion sections of the single studies, the focus here is on more general aspects.

A methodological constraint concerns the small samples of participants with NLD that we were able to include in our studies. It is difficult to recruit large samples of children with this diagnosis for several reasons. NLD is not currently recognized by diagnostic manuals like the ICD-10 (WHO, 1992) and DSM-5 (APA, 2013), despite increasing scientific interest in this condition. Also, its heterogeneity and features mean that NLD has often been confused with other neurodevelopmental disorders (e.g. developmental coordination disorder, ASD or ADHD, to name a few). Further research should therefore strive to involve a larger number of participants.

A second limitation of the present studies consists in the marked variability in participants' ages within each clinical sample. Although evidence suggested that adult-like global-local processing skills develop in children by 7-8 years of age (Kaldy & Kovacs, 2003; Poirel et al., 2008; 2011; Hadad et al., 2010), it is likely that the developmental trajectory of these abilities continues beyond this age. Future studies might reduce this variability by adopting more restrictive criteria in order to analyze visuospatial processing in specific, narrow age groups.

A third limitation consists in some overlaps in the samples of our Study 1 and Study 4. In particular, due to the difficulty in finding participants with ASD without

ID showing low scores on visuospatial intelligence, some participants with ASD without a visuospatial peak were involved in both the studies.

It seems important to mention another matter concerning the types of task used in the present dissertation. A behavioral cognitive method was used to devise our experiments and this enabled us to obtain important information on the visuospatial processing strategies used by participants to deal with a task. Additional information on their strategy use might be obtained by means of noninvasive psychophysiological methods, such as eye movements.

Finally, in the light of the symptomatic proximity between NLD and ASD, expressed in impairments in different domains of cognition, such as motor coordination (Cornoldi, et al. 2016; Frith, 1989; Rourke, 1989; Nydén et al., 2010; Volkmar & Klin, 2000), pragmatics of language, and comprehension of nonverbal social cues (e.g. facial expression, gaze, gesture, and body language) (Landa Klin, Volkmar, Sparrow, 2000; Rourke & Tsatsanis, 2000; Ryburn et al., 2009; Semrud-Clikeman & Glass, 2008), it would be interesting to compare individuals with NLD and ASD using pragmatics of language and social perception tasks as well. This might reveal other cross-disorder similarities and/or differences, further improving our knowledge and clarifying any overlaps in their diagnosis.

6.3 Clinical and educational implications

There are clinical and educational implications to be drawn from our findings, which shed more light on visuospatial processing in individuals with neurodevelopmental disorders, such as ASD and NLD, but also dyslexia and ADHD.

From the clinical perspective, our studies emphasize the importance of considering the different processes involved in each diagnostic test in detail, especially when complex tasks are administered. Our results showed that individuals could use local or global processing, and with more or less success, depending on the requirements of a task and the cognitive domain involved (Dukette & Stiles, 2001). Paying careful attention to the domain being investigated, and to the involvement of global-local processing, would therefore make it easier to interpret the outcome of an assessment effectively.

Our findings may also encourage clinicians to investigate different subsystems of the visuospatial domain by using a variety of tasks. This would enable the identification of strengths and weaknesses in the cognitive profiles of individuals with different neurodevelopmental disorders, and a consequent refinement of intervention programs. A thorough investigation of the visuospatial domain could orient the design of intervention programs to reinforce these skills, given their importance in daily life, at school, and in leisure activities (Cardillo, Caviola, Meneghetti, & Mammarella, 2014; Meneghetti, Cardillo, Mammarella, Caviola, & Borella, 2017). A better understanding of the visuospatial domain might also help in the differential diagnosis, shedding light on the differences between the neuropsychological profiles of the various neurodevelopmental disorders. In particular, it might enable a clear distinction between the visuospatial profiles of children with NLD and those with ASD, two disorders that have posed a diagnostic challenge because of their similarities in some symptoms (e.g., Cornoldi et al., 2016; Williams et al., 2008). Our studies clearly indicate that an in-depth analysis of both visuospatial abilities and global-local processing is the key to distinguishing NLD from ASD without ID, and that these profiles are more different than was previously believed. Furthermore, we cannot forget to make a speculation on how our findings fit into the extant neurobiological models. Some recent studies found for example differences in the corpus callosum area (in particular, in the selenium) only for children with NLD (Fine, Musielak, & Semrud-Clikeman, 2014). In addition, differences in the amygdaloid volume were observed in individuals with ASD, showing larger volumes than the NLD and control groups (Semrud-Clikeman, Fine, Bledsoe, & Zhu, 2013). Finally, both ASD and NLD revealed a smaller volume of the anterior cingulate cortex compared to the control group (Semrud-Clikeman, et al., 2013). The existence of clear differences between these disorders in the atypical functioning of specific brain areas linked to the behavioral symptoms has not yet been demonstrated. For this reason, future studies connecting the neuroanatomical/neurofunctional data with behavioral data will be an important next step for our understanding of these disorders (Semrud-Clikeman, Fine, & Bledsoe 2016).

In addition, given the heterogeneity of the profiles and the overlap of some symptoms, our findings are consistent with a dimensional (e.g. DSM 5; APA, 2013) rather than a categorical approach for the distinction among these neurodevelopmental disorders, showing that an exact boundary between different profiles couldn't be drawn. A dynamic concept might better explain the findings emerged viewing developmental disorders as alternative developmental trajectories in the emergence of representations within neural networks. Initial differences in the same parameter can lead to very different outcomes, and conversely different starting states can sometimes result in similar end states (Oliver, Johnson, Karmiloff-Smith, & Pennington, 2000).

As for the educational implications of our findings, establishing that individuals with different neurodevelopmental disorders have heterogeneous visuospatial performances depending on their neuropsychological profiles might encourage the provision of training activities tailored to these children's specific characteristics. For example, the finding that individuals with ASD but no ID have different visuospatial ability profiles depending on their cognitive level might prompt the use of different educational strategies. It could be useful to teach children with ASD who have no visuospatial peak to make a flexible use of global-local strategies, depending on the task in hand, and to give them more time to complete certain activities or memorize visuospatial information. Establishing that individuals with ASD with a visuospatial peak have a local bias in visuo-constructive tasks could support the use of teaching activities designed to help these children see beyond the details and use integrative/global strategies in this kind of activity. On the other hand, the marked deficits in all visuospatial domains seen in individuals with NLD, and their difficulty in shifting from global to local processing in visuo-constructive tasks, and from processing low-complexity to high-complexity stimuli in perceptual tasks, might encourage the provision of multi-faceted, tailored interventions. With children who have NLD, clinicians and educators might use different approaches, such as remedial intervention to train impaired skills directly, compensatory instruments to bypass the areas of weakness (e.g. assistive technology), and specialized methods to teach the children strategies to improve their skills (Telzrow & Bonar, 2002). For example, intervention on VSWM (e.g. Mammarella, Coltri, Lucangeli, & Cornoldi, 2009), or visuospatial and visuomotor skills could be particularly useful in primary-school age (Cornoldi et al., 2016). Training activities can also be used to help these children choose global rather than local processing strategies more flexibly. Similarly, knowing that children with dyslexia have a slight difficulty with complex materials in visuo-constructive tasks and a processing speed deficit could prompt teachers to allow them more time to complete certain activities, and to limit the use of tasks with time limits, or demanding the management of complex visual stimuli. Similar considerations might be used with children who have ADHD, who showed impairments in visuospatial processing speed, and some difficulties in visuo-constructive tasks: VSWM interventions could help them to overcome their difficulties in this domain (Klingberg et al., 2005).

To conclude, investigating visuospatial abilities and global-local processing in individuals with neurodevelopmental disorders is a highly complex issue. There is still space for further research on the domains of visuospatial abilities, and on the general neuropsychological functioning of children with ASD and NLD. The present dissertation was an effort to raise and clarify some points, but other questions remain open and will require further studies.

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